Industrial Energy Efficiency

CLEAN ROOMS AND LABORATORIES FOR HIGH – TECHNOLOGY INDUSTRIES

CEC Project Manager: **Clint Lowell**
CIEE Project Manager: **Carl Blumstein**
LBNL Project Manager: **Dale Sartor**

DECEMBER 1999
CALIFORNIA ENERGY COMMISSION

Legal Notice

Acknowledgements

Special thanks are extended to the California Institute for Energy Efficiency (CIEE) and the project advisory committee for their long-term support of this project.

- Principal Investigators:
  - Dale Sartor, Lawrence Berkeley National Laboratory
  - Robert J. Tsal, Netsal & Associates
  - Ed Arens, U.C. Center for Environmental Design Research
  - Karl Stum, Portland Energy Conservation Inc.
- Other Investigators:
  - Bill Tschudi, Lawrence Berkeley National Laboratory
  - Cliff Federspiel, U.C. Center for Environmental Design Research
  - Geoffrey Bell, Lawrence Berkeley National Laboratory
  - John Busch, Lawrence Berkeley National Laboratory.

Table of Contents

Table of Contents (continued)

Table of Contents (continued)

Table of Contents (continued)

List of Figures

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliability energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (the Commission, Energy Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Residential and non-residential buildings end-use energy efficiency
- Industrial, agricultural, and water end-use energy efficiency
- Renewable energy technologies
- Environmentally preferred advanced generation
- Energy-related environmental research
- Strategic energy research.

In 1998, the Commission awarded approximately $17 million to 39 separate "transition" RD&D projects covering the 5 PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Energy Efficiency in Clean Rooms and Laboratories for High Technology Industries project, 1 of 9 projects conducted by California Institute for Energy Efficiency. This project contributes to the Industrial Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.state.ca.gov/research or contract the Commission at (916) 654-4628.

Executive Summary

California's laboratories and clean rooms have unique needs for controlled environmental conditions that are extremely energy-intensive. The HVAC energy intensities for these buildings are 4 to 100 times higher than the average commercial building. This market is large and growing rapidly with the trend toward even more energy-intensive spaces. In California, these facilities consume about 2 GW of electrical demand, approximately 9.4 billion kilowatt-hours of electricity, and 25 trillion BTUs of natural gas each year.

Our research has shown that there are major opportunities for energy savings in this sector. Key findings include:

- Savings of 30 to 50 percent of the building's energy use are achievable using current technology.
- The target for energy savings should often be the heating, ventilating, and air conditioning (HVAC) systems, which can account for 50 percent or more of the total energy use.
- Laboratory fume hoods drive a large fraction of the HVAC energy. A new technology for fume hood design developed by LBNL can save up to 70 percent of conventional design.
- There is wide variation in the efficiency of existing HVAC systems.
- Despite widespread industry perceptions to the contrary, energy costs can be controlled in buildings for high technology industries.

The opportunities for improving the energy efficiency in this building type cut across a large number of diverse industries. Figure 1 shows the percentage of total electrical consumption in the high-tech building sector in California by various industries.

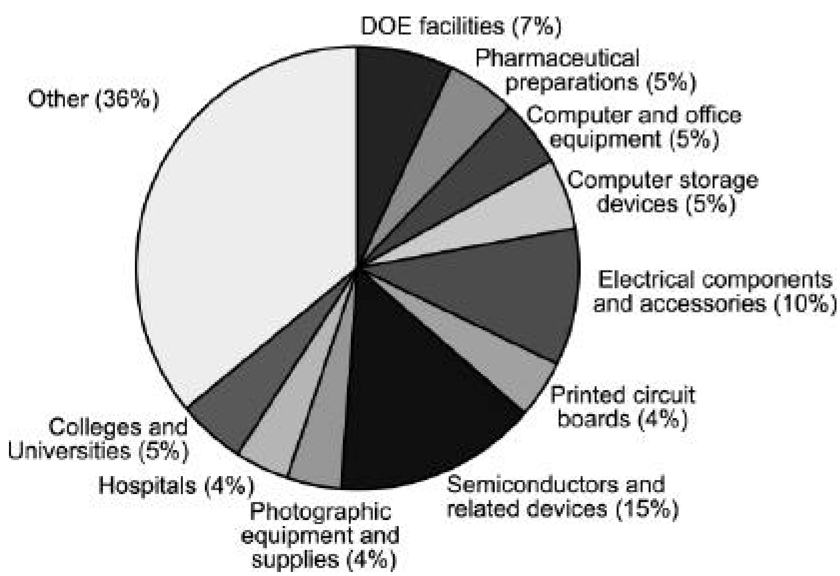

Figure 1. High Tech Industrial Building Electrical Consumption

Project Goals

Eight project components were identified. Each component has a goal to serve as the basis of a multi-year RD&D effort to improve energy efficiency in high tech buildings. We report on this year's objectives, outcomes, and conclusions for each project component and our progress towards reaching the goal. The eight project components and goals are:

1. Design Intent Documentation: Develop a methodology and a tool to capture design intent information and performance expectations for use throughout the building's life cycle.
2. Laboratory Fume Hood Containment: Reduce fume hood airflow requirements by at least 50 percent while improving hazard containment. An additional goal is to develop the containment technology for use in other industrial ventilation applications such as for semiconductor manufacturing.
3. Laboratory Airflow Design: Develop airflow design criteria and tools to optimize fan power consumption.
4. Field Studies/Performance Feedback: Develop a standard methodology for benchmarking complex laboratory facilities. Provide performance feedback to designers and operators.
5. Technology Transfer: Develop design guides, Web sites, workshops, and other technology transfer mechanisms.
6. Clean Room Benchmarking: Improve energy efficiency and performance of clean rooms through benchmarking across industries.
7. Clean Room Analysis Tools: Develop HVAC energy analysis and design tools for clean rooms.
8. Industry Liaison: Form collaborative alliances with industry organizations to assure success in the marketplace.

Project Objectives

This year's project objectives for each project component are summarized:

1. Design Intent Documentation:
   - Implement a scheme to archive design intent information in a prototype, or first generation database.
   - Capture design intent information from a case study of the Design Guide (see below).
2. Laboratory Fume Hood Containment:
   - Continue to develop and test prototype low flow fume hood.
   - Continue to use CFD modeling to evaluate and improve performance.
   - Continue commercialization efforts.
3. Laboratory Airflow Design:
   - Initiate development of a computer program for modeling dynamic multi-fan airflow.
   - Develop initial commercialization plan.

4. Field Studies/Performance Feedback:
   - Continue laboratory benchmarking tool development – add buildings and data to the database, populate a second generation database, analyze data with intent of improving the performance benchmarks, improve reporting scheme, consider integration with design intent tool (see above), integrate information based on aggregate data into the electronic Design Guide (see below), study opportunity to establish a World Wide Web interface to the database and reports, and develop plan to further collect field data and populate the database.
5. Technology Transfer:
   - Continue to support electronic Energy Efficient Laboratory Design Guide – maintain Web version, distribute floppy disks, continuously evaluate Guide based on case study and industry feedback, and make appropriate revisions.
   - Continue case study of Guide's use on a new California laboratory.
6. Clean Room Benchmarking:
   - Continue benchmarking work, including collection of most recent monitored data, refinement of metrics, and expansion of case studies.
   - Disseminate case studies on LBNL's clean room Web site.
7. Clean Room Analysis Tools:
   - Continue evaluation of clean room analysis tool needs and the potential enhancements to an existing computer-based energy analysis tool (potentially DOE-2.2).
8. Clean Room Industry Liaison:
   - Host and document a clean room design charrette.
   - Attend and participate in clean room industry forums to transfer knowledge, expand network, and build industrial relationships.

Project Outcomes

This year's project outcomes for each project component are summarized:

1. Design Intent Documentation:
   - Developed a first generation database in an MS Access to archive design intent information.
   - Captured design intent information from the UC Santa Cruz case study of the Design Guide.
2. Laboratory Fume Hood Containment:
   - Continued to develop and test a prototype low flow fume hood using a commercial hood as the base.
   - Continued to use CFD modeling to evaluate and improve performance.
   - Continued commercialization efforts including arranging for two field tests, and identification of institutional barriers to adoption of the new technology.

- Option agreement signed with ATMI to develop and commercialize products for the microelectronics industry using the low flow containment ("air dam") technology.

3. Laboratory Airflow Design:
   - Initiated development of a computer program for modeling dynamic multi-fan airflow, including analysis of existing software tools that could reduce development time.
   - Developed an initial commercialization plan involving public goods funding, ASHRAE, and private sector software support.
4. Field Studies/Performance Feedback:
   - Continued laboratory benchmarking tool development including adding buildings and data to the database, and populating a second-generation database (in MS Access).
   - Analyzed the data and refined the performance benchmarks, and improved the reporting scheme.
   - Added listing of values for key performance parameters so they can be used in the design intent tool (see above) and compared to actual values when performance is tracked (BLISS).
   - An insufficient number of laboratories were studied to transfer additional information to the electronic Design Guide (see below).
   - Studied the opportunity to establish a World Wide Web interface to the database and reports, and concluded that this is the best implementation strategy.
   - Determined that collection of field data to populate the database is dependent on further funding, however, strong interest was shown by EPA to use the database in a national program (Laboratories for the 21st Century) which may provide a large source of laboratory benchmark data.
5. Technology Transfer:
   - Continued support of the electronic Energy Efficient Laboratory Design Guide – maintained a Web version, distributed floppy disks, continuously evaluated Guide and made appropriate revisions.
   - Continued case study of Guide's use on a new California laboratory and initiated second case study at UC Santa Cruz.
6. Clean Room Benchmarking:
   - Continued benchmarking work, including, refinement of metrics, and expansion of case studies.
   - Arrangements have been made with PG&E to begin a major data collection effort in FY2000.
   - Disseminated case studies on LBNL's clean room Web site.

7. Clean Room Analysis Tools:
    - Continued evaluation of clean room analysis tool needs and the potential enhancements to an existing computer-based energy analysis tool (potentially DOE-2.2)
    - Determined that although a technical need exists, designers are satisfied with their existing tools and have little incentive at the present to change.
8. Clean Room Industry Liaison:
    - Hosted a clean room workshop and published the proceedings which were distributed to all attendees.
    - Hosted two clean room design charrettes, one with Genentech and one with a major San Jose electronics company.
    - Attended and participated in numerous clean room industry forums to transfer knowledge, expand network, and build industrial relationships.

Recommendations for Future Activity

Based on our findings we have identified a number of important areas needing further work. Several of our multi-year tasks are incomplete and should be taken to completion to receive maximum public benefit. Other new research areas hold great promise to help California Industry to ultimately achieve a 50 percent energy saving for these facilities. One of the first new tasks will be to prioritize the many opportunities for energy efficiency research for these building types with Industry participation. The following key focus areas represent our preliminary assessment of the most important research areas:

- Continuation of Priority Tasks:

  We recommend completion of the following multi-year tasks which have made significant progress to date:

  – Complete the Design Intent Tool by developing a Web-based tool. Utilize the tool in a field test on a trial basis and implement any necessary changes.
  – Continue ultra low flow fume hood development including support for field tests, and strategies for overcoming code and institutional barriers. Develop new performance test standards to accommodate the new technology.
  – Develop a computer program to solve the complex equations developed in previous phases bringing a new air flow design tool to market for use in high tech buildings.
  – Completer laboratory benchmarking tool
  – Update and enhance the Laboratory Design Guide.
- High Priority New Initiatives:
  – Development of Research “Roadmap” with industry participation to define priorities for future efforts.
  – Develop a Clean Room Energy Programming Guide to assist designers and operators of high tech buildings to establish and implement energy efficiency measures.

- Development of design and analysis tools:
  - High Tech building energy analysis tool
  - CFD models for clean rooms
  - Full factory energy model.
- HVAC system research:
  - Exhaust minimization in clean rooms
  - Ultra low flow fume hood technology applied to semiconductor equipment
  - Efficiency of scrubbers
  - Air Recirculation efficiency
  - Basis to reduce air changes
  - Development of wide area particle counter
  - Improved efficiency of air handling equipment
  - Research and develop new efficient filter technology
  - Design of efficient ducting systems including sizing, VAV controls, noise cancellation technology.
- Develop heat recovery strategies for High Tech Buildings.
- Develop control strategies to optimize energy efficiency in clean room systems.
- Use of mini-environments within clean rooms.
- Develop new efficient lighting technology, demonstrate use of lighting controls, and develop strategies for use of daylighting in clean rooms.
- Research process systems and plant utilities load characterization and optimize system design.
- Identify and/or develop energy efficient major equipment with industry participation.

The research agenda will be best served through collaboration with other industry efforts. It is essential to collaborate with organizations such as Sematech, ASHRAE, and the Institute for Environmental Sciences as well as individual California industrial firms. Although current research for these building types is minimal, it is desirable to leverage the research by coordinating with the efforts of others.

Abstract

This project utilizes a comprehensive approach for energy efficiency improvement in buildings for high tech industries. High tech industries such as microelectronics and biotechnology play an important and growing role in California's economy. Instead of focusing on specific industries, this project is cross cutting, pursuing the common needs associated with their specialized buildings. Laboratory and clean room facilities consume a significant portion of the energy used by these industries. These facilities are 4 to 100 times more energy intensive than average commercial buildings. Overall cost of energy in these facilities (in California) is over $0.5 billion / year. Energy is primarily used in Heating Ventilating and Air Conditioning (HVAC) systems that often involve very large ventilation loads and special energy intensive environmental control systems. The project involves long and short-term research initiatives as well as significant technology transfer and industry liaison activities. Major components of the project include:

- Design Intent Documentation: Capture design intent information and performance expectations for use throughout the building's life cycle.
- Laboratory Fume Hood Containment: Reduce fume hood airflow requirements by at least 50 percent while improving containment.
- Laboratory Airflow Design: Develop airflow design criteria and tools to optimize fan power consumption.
- Field Studies/Performance Feedback: Develop methodology for benchmarking complex high tech facilities. Provide performance feedback to designers and operators.
- Technology Transfer: Develop design guides, Web sites, workshops, and other technology transfer mechanisms.
- Clean Room Benchmarks: Improve energy efficiency and performance of clean rooms through benchmarking across industries.
- Clean Room Analysis Tools: Develop HVAC energy analysis and design tools for clean rooms.
- Industry Liaison: Form collaborative alliances with industry organizations to assure success in the marketplace.

We have found significant opportunities for improving energy efficiency in laboratories and clean rooms using new technologies as well as greater utilization of existing technologies. One product, an ultra low flow fume hood has been developed to the field test and demonstration phase. Another product, the design intent documentation tool is close to introduction. The airflow analysis tool, and the laboratory benchmarking tool require additional R&D prior to their transfer to the market. For clean rooms, we have identified several promising areas where R&D would be beneficial. The electronic version of the Energy Efficient Laboratory Design Guide has been a cornerstone of our tech transfer activities. We are now coordinating tech transfer and outreach with California's utility managed industrial market transformation programs.

Keywords: energy efficiency, high tech industries, microelectronics, biotechnology, laboratories, clean rooms, Heating Ventilating and Air Conditioning, HVAC, ventilation, design intent documentation, airflow analysis, performance feedback, benchmarking, energy design guide, fume hoods.

1.0 Introduction

1.1 Problem Summary

California's laboratories and clean rooms have unique needs for controlled environmental conditions that are extremely energy-intensive. The HVAC energy intensities for these buildings are 4 to 100 times higher than the average commercial building. This market is large and growing rapidly with the trend toward even more energy-intensive spaces. In California, these facilities consume about 2 GW of electrical demand, approximately 9.4 billion kilowatt-hours of electricity, and 25 trillion BTUs of natural gas each year.

Our research has shown that there are major opportunities for energy savings in this sector. Key findings include:

- Savings of 30 to 50 percent of the building's energy use are achievable using current technology.
- The target for energy savings should often be the heating, ventilating, and air conditioning (HVAC) systems that can account for 50 percent or more of the total energy use.
- Fume hoods drive a large fraction of the HVAC energy. A new technology for fume hood design can save up to 70 percent of conventional design.
- There is wide variation in the efficiency of existing HVAC systems.
- Despite widespread industry perceptions to the contrary, energy costs can be controlled in buildings for high technology industries.

Energy costs can be the highest component of operating cost in these energy intensive facilities. High energy costs have a significant impact, especially on the smaller "second tier" suppliers, as well as the manufacturers of "commodity" products such as disk drives.

1.2 Purpose of Report

The purpose of this report is to summarize the public goods research done in the past year, and to document the work completed. This year was a transition between California Utility sponsored R&D and California Public Interest Energy Research (PIER) sponsored by the California Energy Commission. This project was planned for multi-year funding, however, follow-on funding has not been secured. Therefore, the report documents the status of development for several products, and includes significant details in the Appendix to facilitate continuation of the project if and when additional funding is received.

1.3 Project Goals and Objectives

The goal of the project is to develop technologies, transfer those technologies, and stimulate the use of underutilized technologies to achieve a 30 to 50 percent savings in buildings for high tech industries, including laboratories and clean rooms. The target savings is 50 percent of existing consumption (with the baseline use expected to rise):

- 1 GW electric demand
- 5 billion kWh electric use
- 10 TBTU natural gas.

The energy use in these facilities is primarily in Heating Ventilating and Air Conditioning (HVAC) systems that often involve very large ventilation loads and special energy intensive environmental control systems. To address these high loads, the project involves long and short-term research initiatives as well as significant technology transfer and industry liaison activities. Eight project components have been included. Each component has a goal to serve as the basis of a multi-year RD&D effort to improve energy efficiency in high tech buildings. We report on this year's objectives, outcomes, and conclusions for each project component and our progress towards reaching the goal. The eight project components and their goals are:

1. Design Intent Documentation: Develop a methodology and a tool to capture design intent information and performance expectations for use throughout the building's life cycle.
2. Laboratory Fume Hood Containment: Reduce fume hood airflow requirements by at least 50 percent while improving hazard containment. An additional goal is to develop the containment technology for use in other industrial ventilation applications such as for semiconductor manufacturing.
3. Laboratory Airflow Design: Develop airflow design criteria and tools to optimize fan power consumption.
4. Field Studies/Performance Feedback: Develop a standard methodology for benchmarking complex high tech facilities. Provide performance feedback to designers and operators.
5. Technology Transfer: Develop design guides, Web sites, workshops, and other technology transfer mechanisms.
6. Clean Room Benchmarking: Improve energy efficiency and performance of clean rooms through benchmarking across industries.
7. Clean Room Analysis Tools: Develop HVAC energy analysis and design tools for clean rooms.
8. Industry Liaison: Form collaborative alliances with industry organizations to assure success in the marketplace.

1.4 Project Timing (Including Phases)

We have found significant opportunities for improving energy efficiency in laboratories and clean rooms using new technologies as well as greater utilization of existing technologies. One product, an ultra low-flow fume hood, has been developed and is ready for the field test and demonstration phase. Another product, the design intent documentation tool, is close to introduction, while the airflow analysis tool and the laboratory benchmarking tool require additional R&D prior to their transfer to the market. For clean rooms we have identified several promising areas where R&D would be beneficial. The electronic Energy Efficient Laboratory Design Guide has been the cornerstone of our tech transfer activities. We are now coordinating tech transfer and outreach with California's utility-managed industrial market transformation programs.

1.5 Summary of Expenditures

The 1999 budget was $375,000. These funds are fully expended (December 1999).

1.6 Background

High tech facilities, such as research laboratories, pharmaceutical labs, hospitals, clean rooms etc., serve an important segment of the California economy. For example, the biomedical research industry and the microelectronics industry continue to generate job growth in California. Facilities for these industries often have highly specialized ventilation and environmental control requirements. Clean rooms are perhaps the most energy intensive generic building type / use, and together with laboratory-type space, are expanding rapidly in California. All high tech facilities are generally more energy intensive on a per square foot basis than other academic or commercial buildings.

Results of prior market and energy use assessments are summarized:

- Our review of current design practice, and the very processes of design, reveal pervasive and deeply ingrained design practices that fail to capture the potential for energy efficiency in high tech industrial facilities.
- We estimated a potential for 50 percent reduction in energy intensity, primarily through improved (integrated) design, commissioning, and operations.
- Our review of the existing energy data revealed a paucity of sources of information (e.g., end-use profiles, load-shape analysis) that are fundamental to understanding the deeper patterns of energy use in laboratory-type facilities. One current obstacle is the deficiency of clear protocols, survey strategies, and tools for the necessary monitoring and data collection.
- There is a considerable gap between current best-practice in laboratory and clean room design, and typical practice. This opportunity combined with the lack of comprehensive information (in the form of electronic tools or paper-based media) calls for improved transfer of state-of-the-art information to the mainstream practitioners.

Certain technology R&D avenues also emerged from our analysis:

- Clean rooms are the number-one energy-using laboratory type facility in California. The potential for efficiency improvement here is immense, and current practice falls far short of optimum. The challenge concerns both individual technologies and components, and the lack of an integrated design optimization or “systems” approach.
- Ventilation in laboratory and clean room type facilities is a key issue, and the devices currently in use (e.g., fume hoods) are not optimized in terms of either component efficiency or application efficiency.

Other research at LBNL over the past few years has focused on Building Performance Assurance (BPA) through improved Building Life-cycle Information Systems (BLISS). Much information is lost between project life-cycle phases (for example, the design intent), and even within a phase of a building’s life (for example, during the design phase). This lack of information capture and transfer significantly contributes to poor performance of buildings. Most buildings do not perform as designed or originally intended, and this is often unknown to the operators (among others). This is especially true in high tech industrial facilities that undergo more than normal modifications. Ultimately BLISS will address this issue by establishing a standard information infrastructure that will integrate numerous software products (multi-vendor) used from the building's inception through its life. For example, information generated by Computer Aided Design (CAD) would be available electronically for use in a simulation model. The output (and input) would be available for a commissioning program. In turn, the output would be available to a building performance tracking and diagnostics program integrated with the building's Energy Management and Control System.

Initially BLISS will focus on software modules to preserve building information. For laboratory type facilities, a vehicle is needed to carry information about the design intent (programming / functional requirements) through to construction, commissioning, and other life-cycle phases. This would include performance-based information about system capabilities and limitations.

Clean room facilities operate in an important segment of the California economy (Figure 2). They are used in a wide variety of industries including the microelectronics and biotechnology industries, which are among the few in the state that continue to generate job growth. California represents approximately 17 percent of the US clean room stock.

Figure 2. Clean Rooms are Used by Industries Important to California's Economy

With hundreds of air changes per hour, the cleanest of clean rooms exhibit ten to one hundred times the energy intensity of conventional commercial buildings. The efficiency improvement potential has been shown to be large. Research into clean room energy efficiency opportunities is a special niche in the high tech building investigations underway at LBNL. Clean rooms, while having only a small fraction of the floor area, consume over 50 percent of the total energy in this sector and are found in a wide variety of applications (over 30 SIC code categories). This component of the project focuses on opportunities to enhance energy efficiency for heating, ventilating, and air-conditioning (HVAC) in clean rooms. Manufacturing tools have a major impact on the heat loads in clean rooms and are themselves major energy users. While we are examining their influence on the HVAC systems, improvement in energy efficiency of the equipment itself is beyond the scope of this phase of work.

This work is being coordinated with other related work at LBNL and elsewhere. Important partners are industry groups such as Sematech, an R&D arm of the semi-conductor industry that is beginning to address energy performance issues. Another important initiative is taking place in the Pacific Northwest with the Northwest Power Planning Council and the Northwest Energy Efficiency Alliance to promote resource efficiency in the fabrication of microelectronics. The ASHRAE clean room committee is also beginning to address energy issues. LBNL staff have formed alliances with these groups and others interested in clean room energy efficiency, and hosted several meetings to discuss collaboration on advancing clean room technology and performance. We have worked with the Northwest Power Planning Council, and EPA to begin to develop a coordinated research and market transformation agenda. These collaborations have resulted in projects being funded by CIEE, EPA, and NEEA that are more effective and better coordinated. A challenge in working with many clean room owner / operators is the confidentiality surrounding their operation. Potential collaborators whose research is germane to our own, have proven hard to work with because their funding sources and research results are not public. Public goods research and development is needed especially for the small "second tier" companies that can't afford access to the proprietary research.

1.7 Market and Opportunity Assessment

1.7.1 Summary

In 1996, energy use in California high tech facilities was documented in an LBNL report entitled "Energy Efficiency in California Laboratory-Type Facilities." To highlight the current industries and energy consumption for these types of facilities, an update to the report was prepared. This update generally documents that energy use in high tech buildings within California continues to represent an important opportunity for energy savings. The current energy use data indicates that energy consumption is growing in high tech industries involving research and manufacturing.

LBNL updated the energy analysis for the market sectors in California that utilize laboratories and clean rooms. This update involved analysis of energy use data provided by CEC and DOE broken down by SIC code. LBNL obtained an updated market summary performed by McIlvaine Company that provided detailed information on the clean room industry. This data was analyzed to determine the growth in the amount of clean room space since the market was evaluated in 1995 (Using March 1992 data). Most of these areas continued strong growth and generated job growth. The estimated energy consumption of high tech buildings increased to 9.4 billion kilowatt-hours of electricity and 25 TBTU's of natural gas. California has a disproportionately high share of this market, for example California has approximately 17 percent of the U.S. clean room floor area.

1.7.2 Background

Buildings for high tech industries have a large and growing impact on California's electricity consumption. Energy use data provided in the prior LBNL study suggested an estimated total of 8.8 billion kilowatt-hours of electricity and 21 TBTU of natural gas were consumed in 1993 for these buildings. The target building population for the Efficient High Tech Buildings initiative includes laboratory facilities and clean rooms in a number of industries, research, and educational organizations. As such, this market and building type is crosscutting through many segments important to California. Many industries utilize laboratories and clean rooms, including semiconductor manufacturing, semiconductor suppliers, pharmaceutical, biotechnology, disk drive manufacturing, flat panel displays, automotive, aerospace, food, hospitals, medical devices, universities, and federal research facilities. All of these facilities are characterized by energy intensities that are much greater than ordinary buildings. Laboratory facilities' energy intensities are typically 4-5 times higher than typical commercial buildings. Clean room energy intensities may be 10-100 times higher, depending upon the cleanliness classification of the room. Little has been done to improve the energy efficiency of these facilities for a number of reasons.

Frequently, energy use is considered a necessary cost of the production process for clean room operators. Industries using these facilities focus their research and development efforts on their products, leaving building systems design, construction, operation, and maintenance to traditional practices. This typically has resulted in oversized and inefficient systems that operate below their economic potential.

LBNL has participated in a number of industry efforts including EPRI/Sematech and the Northwest Energy Efficiency Alliance and has studied a number of industry and DOE lab case studies to assess the potential for savings. Based upon this and prior work, we conclude that building systems energy savings of 40 to 50 percent are attainable in these facilities.

1.7.3 Market Update

Recent data provided by the California Energy Commission and DOE confirms that the energy use in the industries and organizations utilizing laboratories and clean rooms continues to increase. In a recent report, the California Energy Commission identified electronics and computers as the fastest growing energy users in the industrial sector ("The Energy File," Sept., 1998). We estimate for 1997, 9.4 billion kilowatt-hours of electricity and 25 TBTU of natural gas were consumed in high tech facilities. This segment has shown increases in spite of the migration of new high tech manufacturing facilities to other lower cost areas in the US and internationally.

High tech industries and organizations represent a large market with great potential for future energy efficiency improvement. Research and market transformation directed at buildings for this sector will have important economic impact on the organizations, and will provide all the related benefits of reduced electrical demand, emissions, etc. Further, it will provide technologies that will be applicable to a broader set of building types including commercial buildings.

The updated energy use data illustrates the crosscutting nature for high tech buildings. Many different industries operate these types of facilities in California. Figure 3 shows the percentage of total electrical consumption in the high-tech buildings sector by various industries.

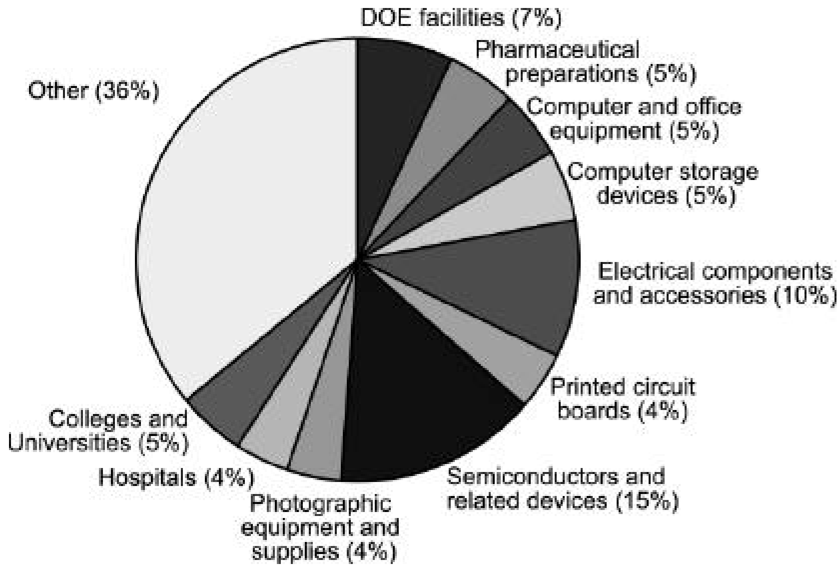

Figure 3. Electricity Use in California High Tech Buildings

In the prior LBNL report, the energy intensive nature of clean rooms compared to other laboratory-type facilities was identified. Figures 4 and 5 below reproduces the Electrical Use and floor area comparisons from the prior report. From these charts, it is apparent that even though the square footage of clean rooms is a small percentage of high tech facilities (12 percent), they represent the majority of the energy use (54 percent).

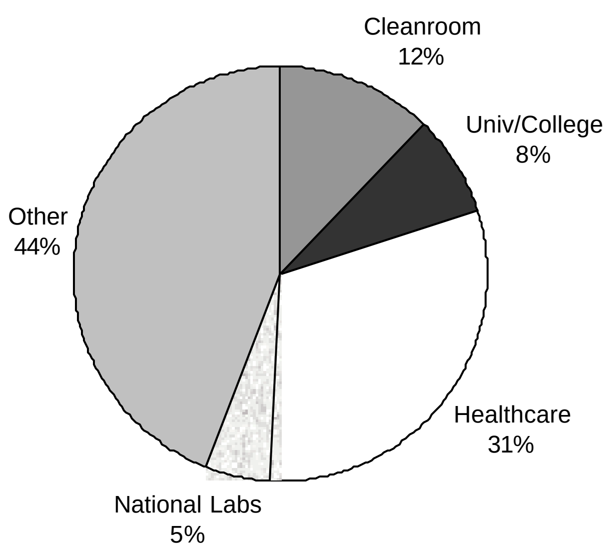

Figure 4. Floor Area of California High Tech Buildings

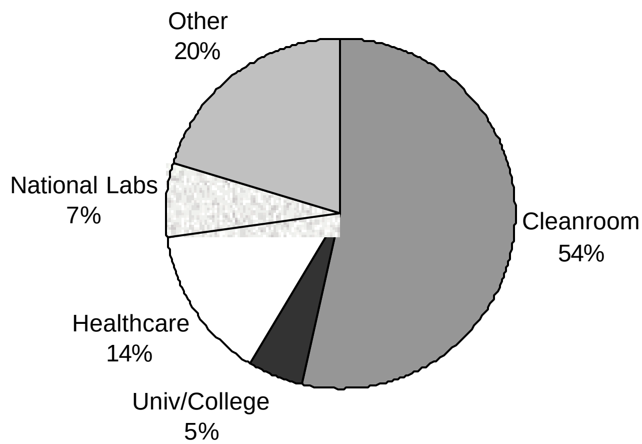

Figure 5. Electricity Use by Building Type

California is the leading state for total clean room floor area and accounts for the largest number of individual clean rooms. Twenty-nine percent of the nation's operating clean rooms and 17 percent of the floor area are located in California according to the McIlvaine Company's market survey. In addition, the trend in overall clean room use is towards higher cleanliness levels which increases the energy intensity.

The industry breakdown showing the number of clean rooms by industry also gives an indication of the crosscutting nature of clean room applications (Figure 6).

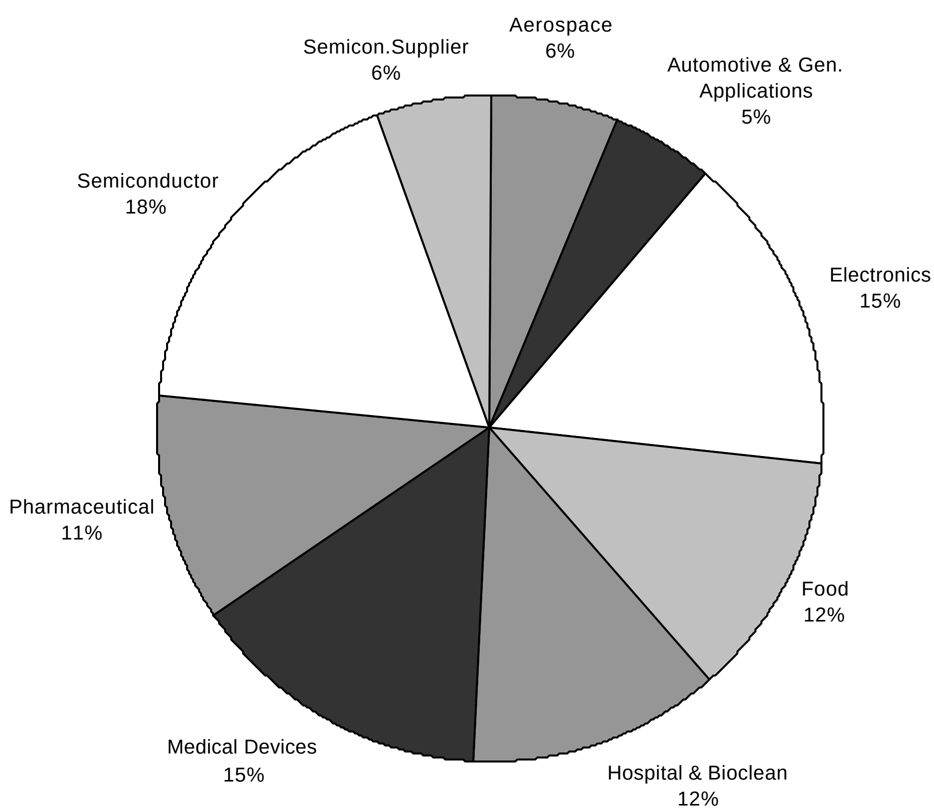

Figure 6. Number of California Clean Rooms by Industry

Although clean rooms are utilized in many industries, the majority of the floor space is concentrated in a few industries. The majority of clean room space is used for semiconductor manufacturing with pharmaceutical / biomedical the second largest user. Figure 7 shows the breakdown of floor area in California clean rooms for industrial uses (excluding government and educational clean rooms). The McIlvaine report identifies that California has approximately 4.2 million square feet of operating clean rooms.

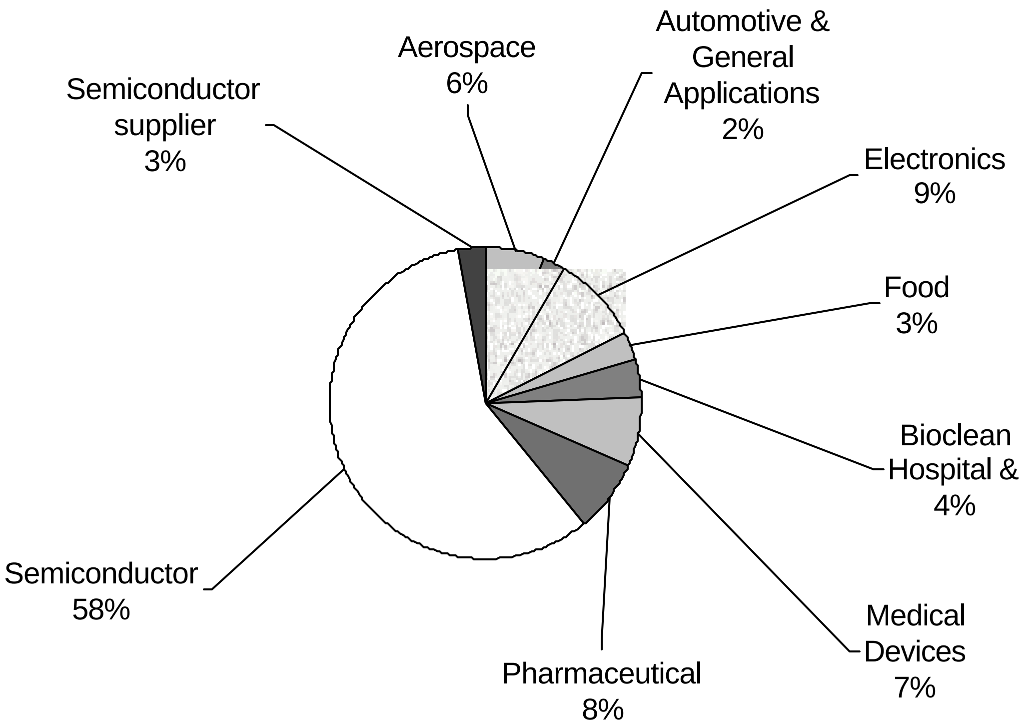

Figure 7. California Clean Rooms by Floor Area

1.8 Description of R&D Approach

The R&D approach was to first take a cross cut look at the market and opportunity for energy efficiency in California laboratories and clean rooms (see above). In conjunction with a Project Advisory Committee (PAC) and with guidance from the California Institute for Energy Efficiency (CIEE) and its Planning Board, a comprehensive multi-year research and development plan was developed. Five key areas of research or market transformation were identified that would yield the biggest returns in this market sector, and lead to achieving the project's goals. These areas are:

- Improved life-cycle information systems including performance feedback to designers and operators
- Reduce exhaust air
- Increase efficiency of airflow design
- Improve clean room efficiency
- Transfer technology and stimulate use of underutilized technology.

The clean room area is more general than the other areas of the program. It was identified as the highest growth area with the largest potential impact, so it was clear that additional R&D would be required. We initially focused on clean room benchmarking, and design analysis tools.

LBNL was selected as the project lead through a competitive procurement by CIEE. The project is managed by the Applications Team (A-Team) at LBNL, which is a joint venture of the lab's Plant Engineering Department, specifically the award winning In-House Energy Management (IHEM) group, and the Building Science researchers in the Environmental Energy Technologies Department (EETD). Sub-project teams were established for each major task. Additional project team members are drawn from other institutions and the private sector. They include:

- Portland Energy Conservation Inc. (PECI) – Experts in building commissioning
- Netsal & Associates – Experts in air distribution system design / optimization
- U.C. Center for Environmental Design Research – Field studies and benchmarking
- Supersymmetry – Experts in efficient clean room design.

The project approach was different for each major task (see below) and is detailed in the individual task reports that follow.

1.9 Major Tasks Conducted

Eight major tasks were conducted in 1999:

1. Design Intent Documentation
2. Laboratory Fume Hood Containment
3. Laboratory Airflow Design
4. Laboratory Field Studies / Performance Feedback
5. Technology Transfer – Laboratory Design Guide
6. Clean Room Benchmarks
7. Clean Room Analysis Tools
8. Clean Room Technology Transfer and Industry Liaison.

Summary reports for each major task follow. In addition, significant information is included in the Appendix, including the final reports or status reports from each of the research teams (on each task).

2.0 Task Reports

2.1 Design Intent Documentation

Goal

Capture design intent information and performance expectations for use throughout the building's life cycle.

2.1.1 Introduction

The goal is to develop a methodology and a tool to capture and preserve design intent information through the building's life cycle to assure that actual performance meets the owner's and designer's intent.

To meet the goal, a design intent documentation tool is being developed (Figure 8). This tool will be electronically linked to the Energy Efficient Laboratory Design Guide to provide a rich resource of design information to the owner and the design team in a structured and useful format. The tool will be used in the programming and early design phase. It starts with the development of design objectives. Objectives are broadly defined design features that qualify performance design goals for the facility. This may be as far as a non-technical owner may go in documenting their intent, however, they should require the design team to develop more quantifiable and verifiable performance metrics that correspond to the objectives. Owners will be encouraged to integrate the energy design objectives, and in fact the design intent documentation tool itself, into their design program. The design program is commonly used as a contract document between the owner and the design team. Use of the Design Guide at the highest level (least technical) is expected when developing the objectives. A second component of the design intent documentation tool will generally be compiled by the design team and will parallel the design objectives, providing documentation as to how the owner's desires will be achieved. This aspect of the documentation will be more structured and quantitative for potential capture into a database. Performance metrics should be measurable and support the qualitative objectives established by the owner. Most of the performance metrics will be developed and refined through the design process. The format of the documentation should be compatible with the International Alliance for Interoperability (IAI) Industrial Foundation Classes (IFC) to facilitate interoperability with other software, and for integration into a database for future use as a building life-cycle information system. Use of the Design Guide for establishing performance metrics will be at lower levels (greater detail).

Improved building life-cycle information systems that document and track building performance will provide owners and operators with information to correct deficiencies, and provide feedback to designers on the success or failure of their designs. Experts in building commissioning and operation estimate that performance tracking can lead to 10 percent or more improved efficiency. This is especially true in the complex and often oversized HVAC systems found in laboratories. Documenting design intent and performance expectations is the first step in commissioning and implementing effective building life-cycle information systems.

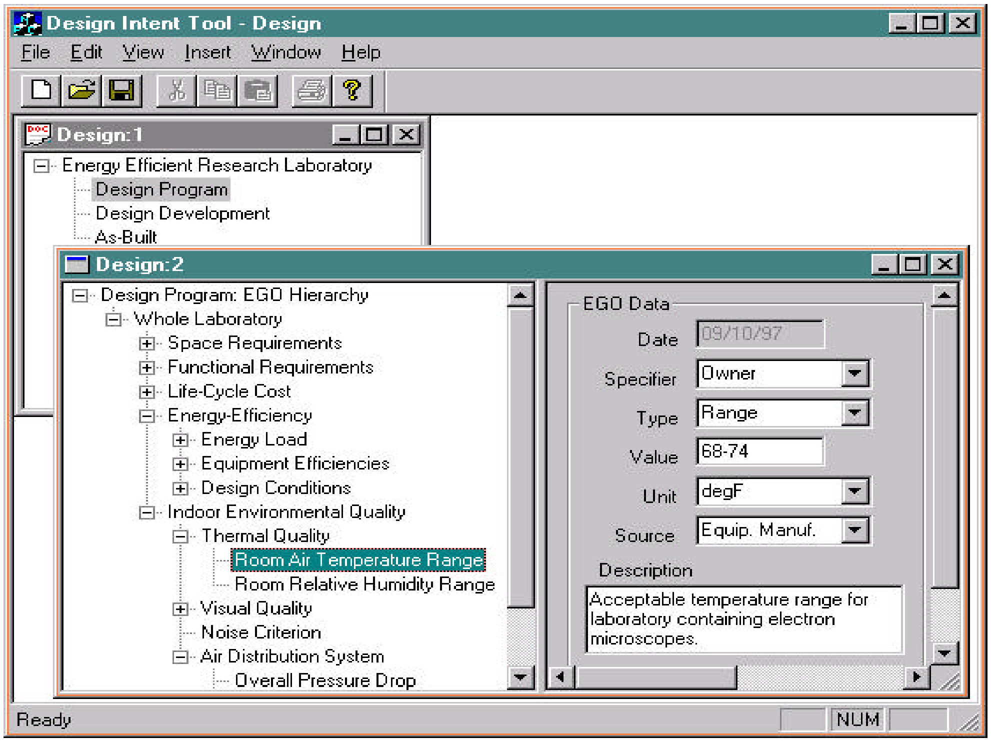

Figure 8. Concept of Design Intent Documentation Tool

2.1.2 Summary of Past Work

Drawing on Building Life-cycle Information System (BLISS) research, LBNL developed a first generation laboratory design intent document. Specific performance objectives were identified for energy efficient design, and a prototype Design Intent Document was completed. A design intent documentation procedure was developed and potential linkages to the Design Guide were assessed. A new science education laboratory, the Elementary Institute of Science (EIS) in San Diego, was identified as a case study to test the energy Design Intent Tool and the Design Guide in an actual design process.

The validation task had four basic elements:

1. Encourage the owner and the design team to utilize the Design Guide.
2. Through meetings, interviews, and design reviews assess the impact of the Design Intent Tool and Design Guide on a facility in the planning phase through the construction bid document phase (and ideally through construction and into the operations phase).
3. Using the prototype Design Intent Tool assist the owner and designer to document the energy related design intent, starting in the planning phase and continuing through contract documents.
4. Provide feedback from the owner(s) and design team for improving the usefulness of Design Intent Tool and Design Guide.

Validation was completed through the planning phase for the Elementary Institute of Science. Valuable information and feedback was obtained and has been reported previously.

The content of the Design Intent Document moved from an outline of the performance metrics to a combination of descriptive text and selection options. A Word™ document template was developed as the design intent tool prototype. Refinements were made to the design intent tool, including the development of a first generation graphical user interface (GUI). The tool was electronically linked to the Laboratory Design Guide. The template included an outline of energy efficiency considerations that provide a document framework, and custom pull down menus that accessed standardized (Excel™) tables to document qualitative project objectives and quantitative performance metrics.

2.1.3 Project Objectives

The objectives in this phase were to:

- Implement a scheme to archive design intent information in a prototype, or first generation database.
- Capture design intent information from a case study of the Design Guide (see below).

2.1.4 Approach

Portland Energy Conservation Inc., a non-profit organization internationally known for their work in commissioning, was brought in as a collaborator and potential commercialization partner in this phase.

2.1.5 Project Outcomes

The following outcomes were achieved:

- Developed a first generation database in an MS Access to archive design intent information.
- Captured design intent information from the UC Santa Cruz case study of the Design Guide.

A procedure for documenting laboratory design intent was developed including potential linkages to the Design Guide. Specific performance objectives were identified for energy efficient design, and a prototype Design Intent Document was completed. The tool was converted from a Word™ document template to an Access™ database. This will facilitate its use in a life-cycle information system including use as the baseline for performance tracking. Integration and electronically linking the design intent tool with the Design Guide is still a high priority, however the interface remains clumsy.

As mentioned under past work, the testing of the guide was combined with validation of the Design Guide. Unfortunately our case study project, the Elementary Institute of Science in San Diego, was delayed. Valuable feedback was obtained during the conceptual design phase, however feedback during the later stages of design was not possible. A second case study was identified at UC Santa Cruz who issued a design program requiring the use of the Design Guide. The Design Guide was effectively used in a value engineering exercise. Based on interviews with the owner, the design intent was documented using the tool, and sample reports were generated (see Appendix).

2.1.6 Technology Transfer

Portland Energy Conservation, Inc. (PECI), a non-profit organization well known for tech transfer work in building commissioning has been added to the R&D team to assist in the development of the Design Intent Documentation Tool and facilitate technology transfer when it is ready for distribution. They were targeted as a potential enterprise to bring the Design Intent Tool to market, and support its use.

2.1.7 Conclusions

Progress on the design intent tool has exceeded expectations. Being able to convert it to a database format was a major step forward and not anticipated to be fully accomplished this year. Further, PECI has added considerable value from a new perspective. They see potential applications of the tool beyond energy and laboratories, for comprehensive design intent documentation on a wide range of building types. When this occurs, it will illustrate the spill over potential of efficiency technology developed for the energy intensive high tech building market.

Commercialization of the Laboratory Design Intent Documentation tool is anticipated through public goods “market transformation” programs. The next step is to finalize the tool development and run some initial tests using the tool as a stand-alone product. The Design Intent Documentation Tool will be introduced to California utilities in 2000 for role out in 2001 (pending continued R&D funding in 2000). It is also anticipated that the DOE Federal Energy Management Program will encourage use of the tool in Federal laboratories. Further, EPA and DOE will assist in commercializing the tool through the newly created Laboratories for the 21st Century program (a voluntary recognition and technical assistance program for private and public labs). It is unclear who will provide on-going technical support for the product, however, Portland Energy Conservation Inc. is well positioned. The application is written in readily available Microsoft software and can easily be modified and customized by sophisticated users.

2.1.8 Recommendations

The next steps anticipated for completion in 2000 pending funding include:

- Application documentation including user manual and “help” function
- Development of the Assessment report (performance tracking potential)
- Report generator for custom reports
- Library of standard objectives, concepts, and metrics
- Focus group to test tool and receive user feedback
- Review of user interface and professional edit
- Improve organization and increase quantitative database fields (to facilitate graphical tracking)
- Web integration.

Development of the design intent documentation tool as a Web product will facilitate links to other resources including the Design Guide for Energy Efficient Laboratories, and a building life-cycle information system. Each listed design objective and performance metric could have a variety of links associated with it that would greatly enhance the user's decision-making process. In addition to support/help text, active links could provide access to information anywhere on the Internet. Links could send the user to product manufacturers, trade associations, code authorities, research organizations, case studies, and even to specific buildings/sites that contain real-time data relating to energy efficiency. Enhanced Web-based reference libraries, and Web page navigation features such as drop-down menus, selective "radio buttons," and check boxes can embellish the design intent tool's functionality and user interface.

The design intent documentation tool will be a valuable component of a future building lifecycle information system (BLISS). Such a system will capture information and track performance throughout a building's lifecycle. As-built and as-operated performance will be compared to the design intent, providing valuable information to the operators, as well as potential feedback to the designers (see Figure 9).

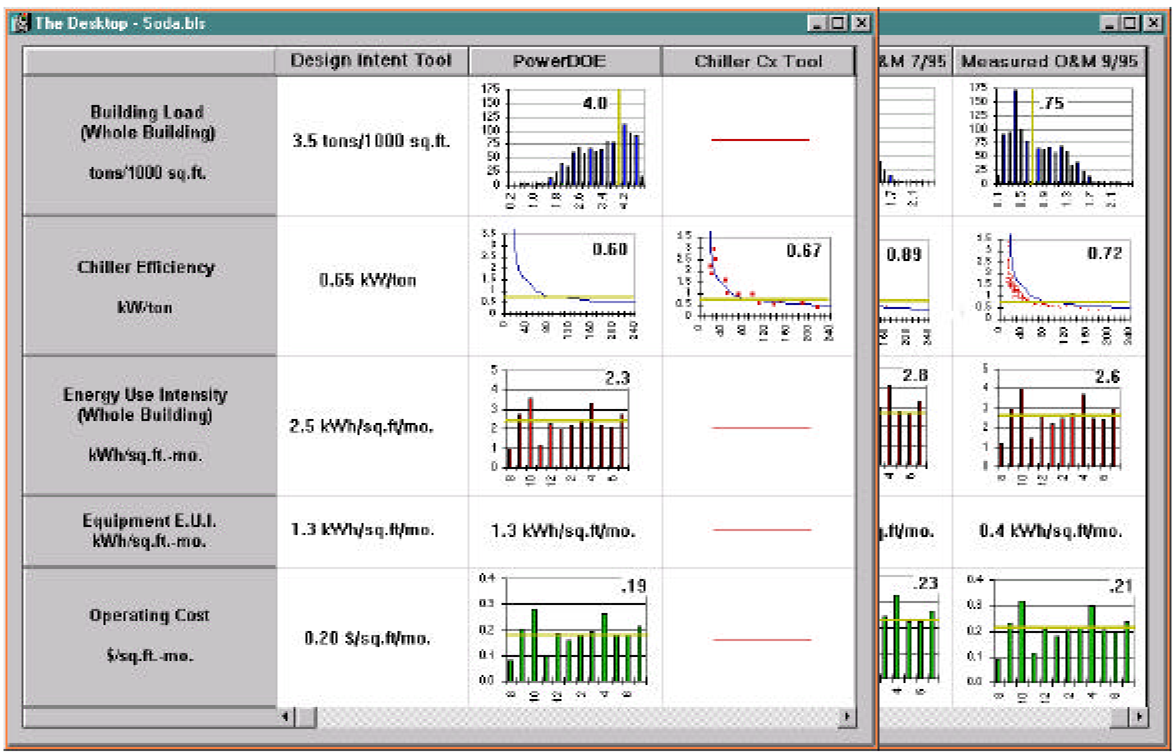

Figure 9. Design Intent Documentation Will Feed Into a Future Building Life-Cycle Information System (BLISS) for Performance Tracking

2.2 Laboratory Fume Hood Containment

Objective

Reduce fume hood air flow requirements by at least 50 percent.

2.2.1 Introduction

Fume hoods are used to protect users from breathing harmful fumes by exhausting large quantities of air. A typical 6-foot hood will draw 1200 cfm 24 hours per day, and indirectly consume more energy than an average house.

Many laboratories have multiple hoods, and it is common for the fume hoods to "drive" the required air changes (100 percent outside air) in laboratory facilities. Therefore, fume hoods are a major factor in making the typical laboratory four to five times more energy intensive than typical commercial buildings (Figure 10). Large quantities of energy are required to move and condition the supply and exhaust air. As 100 percent outside air is used to make-up the exhaust, heating and air-conditioning loads are substantial when the outside air temperature peaks (low and high).

Figure 10. Fume Hoods Often Drive Laboratory Energy Consumption

The state-of-the-art in energy efficient fume hood design uses sophisticated controls on the hood and in the supply and exhaust air streams to provide a constant "face velocity" while varying the air volume. These VAV systems require control of the supply air to maintain a differential pressure between the laboratory and adjacent space (i.e., the corridor) in response to changes in the exhaust rate. If the fume hood sash (a sliding window that protects the user) is open, no savings occur. As the sash is shut, the volume of exhaust air is reduced to maintain a constant face velocity. A minimum air flow of about 25 percent is maintained to dilute and exhaust the fumes. Often users do not properly close the sash, so optimum energy savings is not achieved. Diversity is a term often used to quantify an average operational quantity, or in this case, exhaust air flow. A 50 percent "diversity" factor is typically achieved. In sizing the air distribution and conditioning equipment, many designers assume the sash is open (worst case) especially in the design of the exhaust system. Therefore, VAV fume hoods provide increased safety (constant face velocity) and energy savings (depending on use), but add significant first cost.

The goal of this task is to reduce airflow through laboratory fume hoods by at least 50 percent while maintaining or enhancing containment (safety).

2.2.2 Summary of Past Work

Lawrence Berkeley National Laboratory (LBNL) has developed a promising new Ultra Low Flow Fume Hood technology to reduce the required air flow by over 70 percent while still protecting worker safety (Figure 11). Because of this reduced airflow requirement, air distribution and conditioning equipment can be downsized, resulting in lower first cost. Energy use and peak demand will be significantly reduced. In most cases this invention will remove fume hoods from being the “driver” for outside air and energy consumption in laboratories.

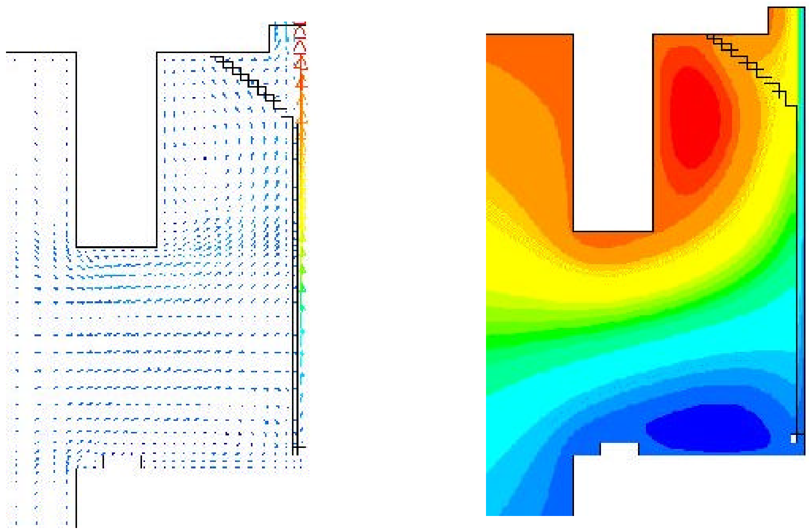

Figure 11. CFD Modeling Was Used to Speed Design Optimization of the Low Flow Hood

The Ultra Low Flow Fume Hood developed at LBNL is much simpler than the state-of-the-art VAV fume hood control system. It operates at a constant volume, and uses no controls. Energy efficiency is not dependent on the operator, and additional cost to the fume hood will be more than offset by reductions in the size and cost of the mechanical HVAC system. Therefore, this invention will lead to lower first cost and significant energy savings. In most cases this invention will remove fume hoods from being the “driver” for outside air and energy consumption in laboratories

DOE and CIEE have supported the advancement of the Ultra Low Flow Fume Hood concept. A second-generation prototype of the advanced containment fume hood was constructed, and refinements to the design were made in 1998. Demonstration of the mock-up generated significant excitement from industry experts including fume hood manufacturers. The prototype was tested by a respected independent professional tester using the industry standard (ASHRAE 110) test procedures, and passed the containment tests at 25 percent of the normal fume hood air flow with a significant margin. A computational fluid dynamic (CFD) model of the hood was created that allowed refinement of the design without continual modification of the mockup. A full patent application was developed by LBNL and submitted to protect the invention.

Two reports are available covering past work, however they contain confidential information. Interested parties who sign or have signed a non-disclosure statement can request copies of the reports.

2.2.3 Project Objectives

The objectives for this phase were to:

- Continue to develop and test prototype fume hood with airflow at least 50 percent below conventional.
- Continue to use CFD modeling to evaluate and improve performance.
- Continue commercialization efforts.

2.2.4 Approach

Research and development of the low flow fume hood is being done at LBNL with industrial partners providing in-kind support. The lead investigator is Geoffrey Bell [(510) 486-4626].

2.2.5 Project Outcomes

The following outcomes were achieved:

- Continued to develop and test a prototype low flow fume hood using a commercial hood as the base.
- Continued to use CFD modeling to evaluate and improve performance.
- Continued commercialization efforts including arranging for two field tests, and identification of institutional barriers to adoption of the new technology.
- Option agreement signed with ATMI to develop and utilize products for the microelectronics industry using the low flow containment ("air dam") technology.

A commercial hood, custom fabricated by our industrial partner to facilitate modifications, was installed at LBNL with a dedicated exhaust system. Modifications were made to incorporate the ultra low flow technology. The test bed was instrumented and calibrated.

Additional work focused on nine subtasks:

1. Fume Hood Patent Review: A comprehensive review of prior, relative patent art and applications was completed to identify all patents relative to chemical/biological fume hoods. Work included performing literature searches for patented features. The resulting information indicates that LBNL will likely sustain its patent claim.
2. Fume Hood Implementation Barrier Identification: Barriers to applying low-flow fume hood technique were identified and analyzed. Barriers with respect to: Uniform Building, Mechanical and Electrical codes; OSHA regulations; Fire and Safety regulations (specifically NFPA); and existing "standard" design guidelines (especially ASHRAE and ACGIH) were studied.
3. Fume Hood Safety and Containment Requirements: Safety and performance issues for fume hoods were reviewed. ASHRAE, CAL-OSHA, and other organizations both public and private were contacted. Potential modifications to existing fume hood test and evaluation procedures were identified.

4. Fume Hood Test Methods: Test procedures to verify the Berkeley hood's performance were considered. Since testing should be performed on a regular basis by a facility's Environmental, Health, and Safety (EH&S) group, the tests must be simple to conduct, inexpensive, and repeatable.
5. Screen Air-Flow Characterization: A study was completed to characterize airflow through a large family of screen-types for the low-flow fume hood. A test apparatus for studying and characterizing airflow through screens was developed. Evaluations incorporated practical application of fluid dynamics including: laminar and turbulent air flow studies; transitional air flow evaluation; wake influences and vortex streets; boundary layer interfaces, and edge effects on fluid flow.
6. Supply Air Plenum Arrangement: Designed and fabricated supply air plenum systems that incorporate various screen-types and methods to achieve equal pressure distribution. Particular effort was committed to analyzing supply air input influences on interior airflow dynamics.
7. Fume Hood Baffle Design: Studied and characterized airflow dynamics of air flowing out of the fume hood through and behind a baffle system. Analyzed flow along flat-plates; evaluated entrance and boundary layer interfaces, alternate baffle designs, equal pressure distribution behind the baffle, and interior airflow dynamics. In addition, the exhaust ductwork connection to the low flow hood was evaluated for geometric configuration and location. CFD modeling continued with emphasis on back-baffle segments.
8. Fume Hood Vortex Development: Analyzed vortex development. Fabricated baffle systems incorporating various arrangements that enhance / defeat vortex development. Employed practical application of fluid dynamics including laminar and turbulent airflow studies and transitional airflow evaluations. Used computational fluid dynamic (CFD) modeling to assist in analysis effort.
9. Fume Hood Operational Envelope: Performed extensive evaluations of an alpha hood including tests per ASHRAE standards. Evaluations incorporated numerous empirical tests to begin establishing the low flow hood's operational envelope, failure modes, and user-interface sensitivity. Hood design refinements were implemented, and modified components fabricated. The hood was re-tested as necessary. Results of these evaluations were shared with our industrial partner. Effective visual containment and ASHRAE testing were achieved with the alpha hood.

2.2.6 Technology Transfer

The market is very excited about this technology. Work progressed to transfer the fume containment technology for both laboratory fume hoods and microelectronic fabrication processes.

Two field tests are being arranged. Montana State University has contracted with LBNL to provide design assistance on their new laboratory. A major focus of this activity will be on deployment of the ultra low flow fume hood, first as a field test in 2000, then in a pilot building in 2001, and later in an entire laboratory building. It is envisioned that other components of our laboratory research will also be incorporated into this project. We have also been working with the University of California to encourage their use of this technology. UC Santa Barbara has shown interest in hosting a field test in their Environment Health and Safety (EH&S) lab. Getting "buy in" from EH&S Industrial Hygienists is critical to the success of the hood in the marketplace. Therefore, this field test will be very valuable.

As a result of our activity to improve clean room efficiency (see other tasks) we have talked to several manufacturers regarding using the containment concept developed for the ultra-low flow fume hood to other applications. Specifically, the concept may be applicable to gas cabinets, exhaust scrubbers, and wet benches. Meetings were held with ATMI, a supplier of equipment to the microelectronics industry. Negotiations were completed, and an option agreement was signed. ATMI will develop and commercialize products for the microelectronics industry using our low flow containment ("air dam") technology. Development is expected to take at least 1 year.

2.2.7 Conclusions

Tests of the technology in the laboratory have been very successful (see Figure 12). Interest in taking the low flow fume hood technology to the field test and demonstration phase has been strong.

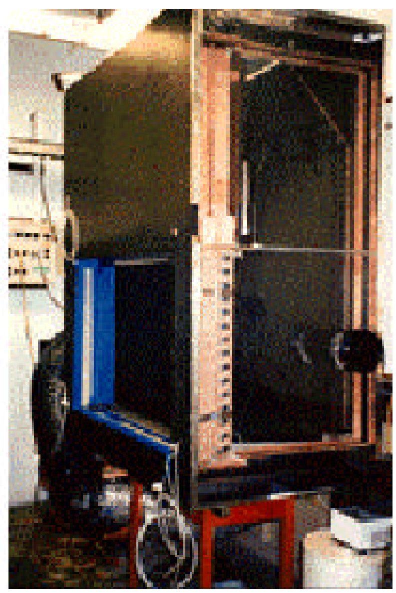

Figure 12. Fume Hood Bench Prototype Passed ASHRAE 110 Test

There has been significant industry interest in the low flow fume hood. LBNL has actively solicited industry partners to bring the invention to the market. Four fume hood manufacturers indicated interest, were interviewed, and one was selected. Our goal was to pick the manufacturer with the greatest commitment and capability to succeed. We are working on an informal basis with this manufacturer to develop the technology for their commercial hood and they will most likely participate in the California field test scheduled for 2000. Concurrently Montana State University has committed to being the first installation of the new fume hood technology, and they have been working with a second hood manufacturer. It is unclear whether it will be in the public's best interest to enter into an exclusive licensing agreement giving one manufacturer the incentive to overcome institutional barriers and market resistance to the new technology, or to license several manufacturers to assure competitive pricing and widespread availability. An option in the latter case is an agent relationship. This option would license a third party to assist in bringing the product to market. This agent would then sub-license to multiple hood manufacturers to supply the product. Several manufacturers of laboratory related products and services have indicated an interest to serve as an agent for the invention (including an exhaust fan manufacturer, a fume hood control company, and an engineering firm).

California Universities and Colleges are adding many hoods to existing, and new, teaching and research laboratories. They are a target for field tests and demonstrations, and will benefit greatly by the reduced operating costs.

The potential dollar savings is highly dependent on the location (climate), efficiency of the cooling plant, efficiency of the air distribution systems (including pressure drop) and the utility rate structure. A rough estimate of savings for California is $1,000 per hood per year. The savings will be higher in more severe climates. The incremental cost for the low flow hood has not been determined, however it is likely to be less than $2,000. Therefore, even if the mechanical system is not downsized (reducing first cost), the "payback" will be under 2 years. Development of a retrofit kit for existing hoods is anticipated after introduction of a commercial Ultra Low Flow Fume Hood in the Year 2000. The "payback" for the retrofit kit will likely be under 3 years. We estimate approximately 85,000 hoods are in use in California. Assuming a 50 percent market potential, the California demand and energy savings from this technology could reach .1 GW and 360 GWh / year (assuming no growth in the number of hoods). Actual savings will be higher in retrofit (significantly more savings with the supply air fan), and the number of new fume hoods in California is anticipated to continue strong growth. Each new hood will save 2.3 kW and 8.5 MWh / year plus 700 therms of natural gas. (See Appendix for savings calculations)

2.2.8 Recommendations

With co-funding from the U.S. Department of Energy ($75,000 in 2000), work will continue to further optimize the performance of the low flow hood technology. This work will be carried on simultaneously and in coordination with the two field tests to be implemented in 2000. We plan to issue an RFP and select one or more industrial partners following the field test(s). It is anticipated that following the successful field tests, research will turn to a low flow fume hood product for the retrofit market.

2.3 Laboratory Airflow Design

2.3.1 Introduction

Goal

Develop airflow design criteria and tools to optimize fan power consumption.

Air flow design has an extraordinary impact on energy use and performance of laboratory type facilities including clean rooms. Designs are often based on historic rules of thumb rather than minimum life cycle cost. LBNL is developing airflow design criteria and tools to optimize fan power consumption (Figure 13).

Figure 13. Duct Design is Rarely Optimized

Negative pressure confinements are very important for many laboratories dealing with hazardous substances. Conversely positive pressure confinements are used in many clean rooms to prevent contamination. Negative or positive pressure drives air infiltration or exfiltration, and creates leakage through doorway slits and construction cracks. High pressure differences in the workspaces are undesirable. If infiltration or exfiltration exceeds design limits it may result in room over- or under-pressurization, loss of pressure zoning, substantial heat and energy loss, dust and dirt carryover, and airflow destabilization. The need to calculate flow distribution and internal static pressure occurs any time that an engineer is studying the effect of airflow system performance and control. The necessity for simulation appears in many HVAC designs, such as determining system operating performance, investigating system stability under different operating conditions, system retrofitting, emergency conditions and accidents, fire / smoke protection systems, pressure and airflow balancing after system modification, and equipment failure.

Currently engineers have no practical technique to calculate actual airflow, pressures, and fan operating points in dynamic multi-fan laboratory systems. Actual operating conditions vary and can result in under or over pressurization, imbalance, and airflow destabilization beyond design limits. Such conditions can be inefficient, unsafe, and negatively impact the work being done in the building.

The goal of this project is to develop methods and a numerical model capable of analyzing HVAC equipment, control elements, laboratory equipment, and laboratory spaces as one generalized system. Constant volume, variable volume, and central supply with many exhaust airflow systems are considered. The objectives are to determine the air flows and pressures in a steady-state condition after the initial data, such as the position of fume hood sashes, are fixed and the control sensors, controllers, and actuators have already established stability. Statistical analysis of open / closed fume hood sashes based on their schedules will allow analyzing the effect of pressurization and evaluating the efficiency of a generalized air distribution system. This multi-year project will consist of developing a multi-fan laboratory airflow distribution computer program including computer code development, data base population, and testing.

The economic goals are to improve and optimize the lifecycle cost effectiveness of airflow design in high tech buildings. High airflow is a major energy driver in laboratories and clean rooms, often accounting for 30 to 40 percent of the total facility energy use. Therefore, a 50 percent reduction in the average pressure drop (say from 4” to 2”) will reduce the overall energy consumption by 15 to 20 percent. Note that other tasks designed to reduce the total airflow (e.g., the low flow fume hood) will reduce the potential savings from optimum design of the airflow system (these energy savings interact). However, the interaction can also be positive, for example smaller fan horsepower will reduce the cooling load.

2.3.2 Summary of Past Work

LBNL produced an Airflow Design Guide. The guide was developed to provide guidance for resistive elements in the air supply and exhaust systems of research laboratory facilities. This guide utilizes a systems approach to generalize design criteria for such design parameters as duct airspeeds. Dr. Robert Tsal prepared the technical content of the Airflow Design Guide. Dr. Tsal is an international expert on duct design having authored the last three editions of the ASHRAE Fundamentals chapter on duct design, as well as being the principal investigator on several related ASHRAE research projects. His report was edited and reformatted to match the existing (energy efficiency) Design Guide. To enhance its usefulness, the Air Flow Design Guide was fully integrated with the electronic Design Guide (see subsequent task).

Engineers have no practical technique to calculate actual airflows, pressures, and fan operating points in dynamic multi-fan laboratory systems. In 1998 development of a numerical model of multi-fan air distribution systems for research laboratories was initiated to expand and enhance existing Airflow Design tools. This project defined the problem and developed the theory (numerical methods) for a model of a two-fan system including determination of air pressure in the workspace (typical configuration in a laboratory). The model includes variable air volume and constant volume systems. This effort built on the ASHRAE recommended T-method for duct simulation.

The project was divided into the following tasks:

- Problem definition
- Analysis of existing methods
- Problem formalization
- Numerical model development and convergence study
- Software implementation plan development.

The development of numerical models to simulate complicated, two-fan HVAC systems employed in laboratories has been completed. Work focused on the mathematical formulation and formalization of the airflow distribution systems as well as the search for an efficient numerical method for solving large systems of simultaneous nonlinear algebraic equations. A report from Dr. Robert Tsal on the numerical model(s) developed was included in a previous report, and is included in the Appendix of this report for completeness.

The cost of developing the computer program and bringing it to the market would require a significant budget. The project was therefore divided into increments to allow us to proceed, and we continue to explore partnering opportunities with other funding sources.

2.3.3 Project Objectives

The objectives for this year's work included:

- Initiate development of a computer program for modeling dynamic multi-fan airflow.
- Develop initial commercialization plan.

2.3.4 Approach

The development work on the computer program and initial commercialization plan for modeling dynamic multi-fan airflow was done under contract to Robert Tsal, of Netsal & Associates, an international expert in duct design and analysis.

2.3.5 Project Outcomes

This year's work resulted in the following outcomes:

- Initiated development of a computer program for modeling dynamic multi-fan airflow, including analysis of existing software tools that could reduce development time.
- Developed an initial commercialization plan involving public goods funding, ASHRAE, and private sector software support.

Netsal & Associates initiated development of a computer program for modeling dynamic multi-fan airflow. The use of existing software tools, particularly SPARK and GenOpt, were evaluated for their potential to shorten implementation time and provide interfaces to other building energy / design software. After reviewing Spark for use as the solver, it was rejected for this application. Likewise, GenOpt was also rejected due to the complexity of the optimization problem. Work on a commercialization plan was initiated, with ASHRAE being identified as a potential commercialization partner.

See Appendix for a complete technical report on this task.

2.3.6 Technology Transfer

The principal investigator, Robert Tsal, is active in ASHRAE, and continues discussions regarding potential collaboration on improved airflow analysis and design tools. ASHRAE has been identified as a commercialization partner for the Airflow Design Tool and may share in the cost of developing the computer program.

2.3.7 Conclusions

Improving design practices with better rules of thumb, and design tools is a public goods activity. There is little commercial potential to sell such tools at a profit. Therefore, these tools need to be developed with public goods funds, and will likely be brought to the market through technology transfer and market transformation programs. Private interests may be willing to enhance, distribute, and support such products in the marketplace once they are developed.

High development cost has put this task on a slow track. The design guide and other technology transfer activities will increase awareness of airflow optimization, however, development of improved tools will require a significant investment of public goods funding.

2.3.8 Recommendations

A 2 to 3 year effort funded at $100 to $150,000 per year is required to develop a computer analysis tool (simulation and optimization) based on the numeric models developed to date.

2.4 Laboratory Field Studies/Performance Feedback

Goal

Develop a standard methodology for benchmarking complex high tech facilities. Provide performance feedback to designers and operators.

2.4.1 Introduction

LBNL in conjunction with UC Berkeley's Center for Environmental Design Research (CEDR) has initiated a project to provide feedback to designers and operators of actual laboratory loads and field performance. The ultimate goal of this field assessment is fourfold:

1. Provide benchmark information on laboratory energy performance
2. Confirm and quantify the problem of oversizing
3. Document the potential impact of measures to mitigate the performance impacts of oversizing (these include controls – such as VAV and VFDs, design for high part-load efficiency, and commissioning)
4. Eventually change the standard practice of oversizing laboratory HVAC equipment (i.e., overestimating process loads) and the resulting performance penalties.

It is envisioned that the development of laboratory performance measurement protocols will lead to the development of a database of laboratory performance information that will help to lower the uncertainty in assumptions used during the design process. The data will also be available to energy engineering and research professionals to assist with analyses of various types. These protocols will also facilitate continued collection of performance data in a standardized way.

The economic goal of benchmarking and performance feedback is to provide economic and functional yard sticks for facility owners, designers, and operators to measure how their facilities compare to averages and best practices. The economic benefit for benchmarking and providing performance feedback is difficult to quantify, however it is necessary in order to overcome the market barriers created by continued use of poor design assumptions, and a lack of knowledge or trust in the efficiency opportunities that are available. It is argued that "you can't manage what you don't measure."

2.4.2 Summary of Past Work

UCB CEDR developed prototype short-term laboratory measurement protocols and applied them in one UCB laboratory building. The protocol used short-term monitoring techniques to measure chiller use, equipment plug loads, and lighting energy. Results of the monitoring were compared to design assumptions. This work resulted in documentation of extensive over-sizing of the system compared to actual loads encountered.

Subsequent tasks included:

- Identification of Field Elements for a Data Depository: Ultimately the data depository will support design decisions and provide performance metrics for benchmarking laboratory facilities. A workshop with eight experts was used to identify the desirable field elements for a database on actual laboratory loads and performance. Such information is required for benchmarking (to compare facility performance) and to document actual field conditions to encourage part-load performance enhancements and right-sizing.
- Development of Second Generation Short-Term Test Protocols: Based on industry input for a higher priority on benchmarking at a whole building level, development and field testing of a short-term end-use test protocol was not pursued. The protocol developed for this project re-focuses on the field collection of data on a small number of building features.
- Development of First Generation Database: A database was designed and implemented. The database includes descriptive information about each laboratory building as well as design and measured data.
- Refinement of Performance Assessment Methods: Results from metering and other data sources need to be synthesized into meaningful performance metrics useful for comparing one laboratory building to another. This task addressed the analysis requirements. Initial efforts focused on developing potential performance metrics for laboratories in a hierarchical form to allow the user the ability to choose the level of detail provided. However, significant benchmark information (perhaps "overkill") was available at even the highest level of aggregation, so refinement was required. Two methods of performance assessment were ultimately developed. The first is based on a comparison of actual energy consumption to engineering calculations of the ideal (high efficiency) case to determine an energy effectiveness rating. The second is a statistical method to provide comparison of the target building to a larger population.
- Test Utilization of Database: The purpose of this task was to test the database. Utility and building information were obtained for two laboratories and entered into the database.
- Develop Performance Benchmarks: As described above, a benchmarking technique was developed that allows the performance of dissimilar lab buildings to be compared. The concept was to compare the actual energy usage to the minimum theoretical energy usage. Since it is difficult to compute the theoretical minimum, simplifying assumptions are used. Only eight features of the building were used to compute the efficient energy usage. The performance, called the energy usage effectiveness, is defined as the ratio of the highly efficient usage to the actual usage. We expect that this benchmark technique will reduce the ratio of the standard deviation to the mean, relative to that of simply normalizing by plan area, so that the "outliers" caused by significant design problems (such as oversizing) or operating problems can be detected. These calculations have been programmed into an MS Access database. In addition, the performance of a single building is compared to that of a population of buildings.

- Develop a Feedback Mechanism for Designers and Operators: Based on the initial data collected and the benchmarks developed, a reporting scheme was developed to provide feedback to building owners, operators, and designers about the performance of their buildings. A graphical report similar to the EnergyStar benchmarking report was developed. A scatter plot of actual data comparing the target building to the population was added.

Our emphasis in this task has shifted toward identifying data that might be readily available without field-testing (or very limited field-testing). Our discussions with laboratory facility managers have indicated that this is a high priority. Greater reliance will be made on readily available whole building energy use data rather than data requiring additional metering. Such a strategy will yield a larger population of participants and can be considered a first step in the benchmarking process for laboratory type buildings. Benchmarking is critical to providing useful performance feedback. Detailed, end-use metered data can be added later as an option to those laboratory managers desiring higher “resolution.”

2.4.3 Project Objective

The objective for this phase was to continue laboratory benchmarking tool development – add buildings and data to the database, populate a second generation database, analyze data with intent of improving the performance benchmarks, improve reporting scheme, consider integration with design intent tool (see above), integrate information based on aggregate data into the electronic Design Guide (see below), study opportunity to establish a World Wide Web interface to the database and reports, and develop plan to further collect field data and populate the database.

2.4.4 Approach

The U.C. Center for Environmental Design Research did this work. Cliff Federspiel was the lead researcher.

2.4.5 Project Outcomes

The following work was accomplished relative to the objective:

- Continued laboratory benchmarking tool development including adding buildings and data to the database, and populating a second generation database (in MS Access).
- Analyzed the data and refined the performance benchmarks, and improved the reporting scheme (see Figure 14).
- Added listing of values for key performance parameters so they can be used in the design intent tool (see above) and compared to actual values when performance is tracked (BLISS).
- An insufficient number of laboratories were studied to transfer additional information to the electronic Design Guide (see below).
- Studied the opportunity to establish a World Wide Web interface to the database and reports, and concluded that this is the best implementation strategy.

- Determined that collection of field data to populate the database is dependent on further funding, however, strong interest was shown by EPA to use the database in a national program (Laboratories for the 21st Century) which may provide a large source of laboratory benchmark data.

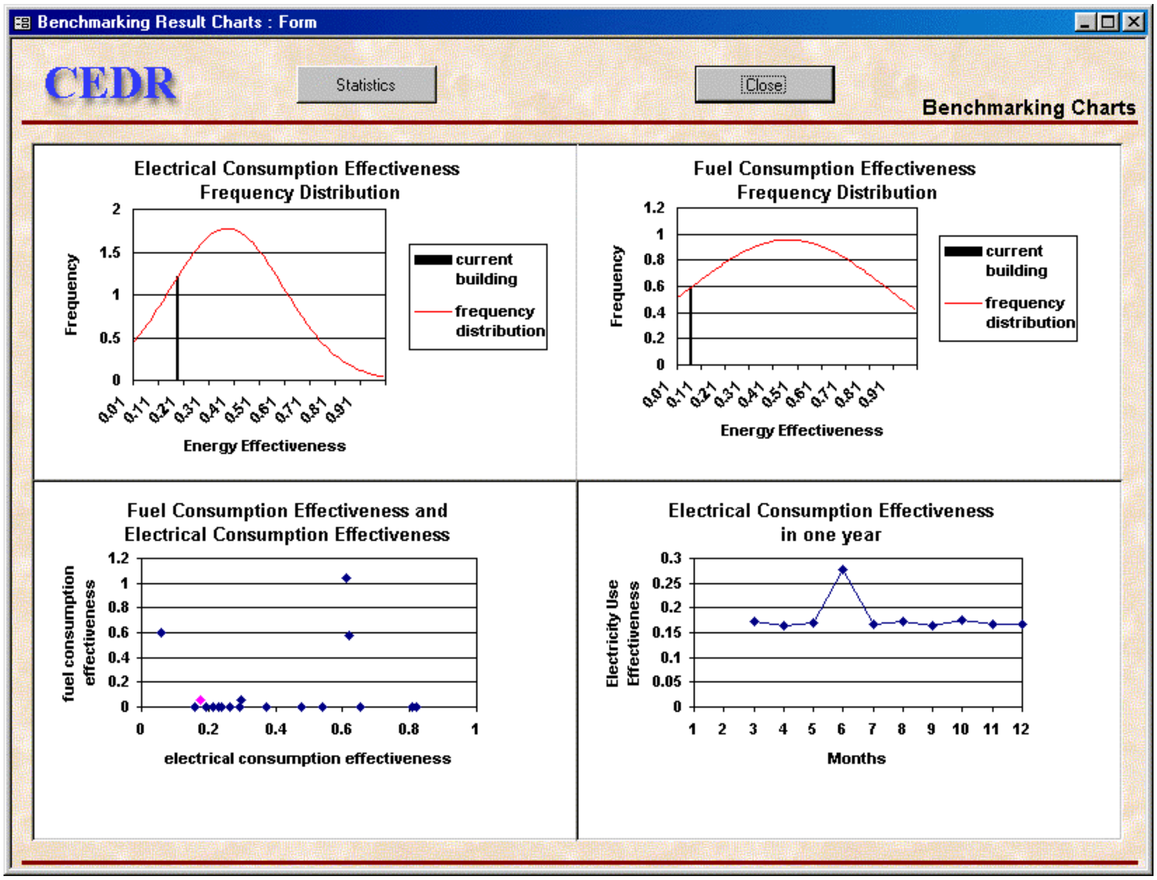

Figure 14. Prototype Laboratory Benchmarking Report

A benchmarking technique was further developed that allows the performance of dissimilar lab buildings to be compared. The concept is to compare the actual energy usage to the minimum theoretic energy usage. The performance, called energy usage effectiveness, is defined as the ratio of the highly efficient usage to the actual usage.

Contacts were made with industry (e.g., Enron and Johnson Controls) regarding adding buildings to the database. Campus buildings were added to the database and many lessons were learned. The benchmarking calculations were modified to allow multiple time intervals of unequal duration (e.g., time period can be synchronized with utility bills). Accounting for partial air-conditioned of buildings was also added. The benchmarking software continued to be debugged. Monthly effectiveness metrics were computed for 20 buildings over a 3-year time period, and the results were evaluated. Issues have been raised relative to data integrity (including metering faults), and perhaps model accuracy. Resolution of these issues was pursued. The user interface was modified to match the look and feel of the Energy Star benchmarking tool (for offices). A second-generation prototype of the benchmarking calculations and database was developed and demonstrated. Two dialog boxes to the benchmarking tool were added to integrate the findings from our benchmarking work with the design intent tool and the electronic Design Guide. One shows parameters used for computing the benchmark and the other shows equivalent performance metrics such as those cited in the design intent tool.

2.4.6 Technology Transfer

Work under this task has been presented in several forums including academic, industry, and one-on-one with interested potential users. A presentation was made at the Laboratories for the 21st Century, a conference attended by 200 professionals in Boston this year and the sponsor, EPA, has shown keen interest in the benchmarking tool. Private companies, such as Johnson Controls have also viewed the prototype and have showed interest.

2.4.7 Conclusions

The method developed under this task is innovative and relatively untested. Developing a "custom" benchmark will eliminate much of the sensitivity to proprietary information and will remove some variables that make building to building comparisons difficult. Further, a benchmarking tool based on very little monitored data is very desirable from the user's standpoint. However, if the technique is so simplified that the results are inconclusive the tool will be of little value. For example, use of a fixed or estimated value for the process or plug loads (non-HVAC and lighting loads) could be a major flaw. Engineering overestimates of the process load often contribute to equipment oversizing. More accurately estimating the process load without a database of actual measured data will be difficult. Hence the use of this tool will fall short relative to the goal of quantifying the problem of oversizing. The solution calls for a multi-level tool that allows the user to enter and obtain value with minimal input (as is the case now), while providing the opportunity for greater analysis with the availability of more data (as was proposed earlier in the project).

Given the difficulty of estimating the economic value of benchmarking and performance tracking, it is unlikely that such information could be collected and sold at a profit to high tech facility managers. It is more likely that such a service, or at least the database, will be established and maintained with public goods funding. It is possible that with the newly created Laboratories for the 21st Century, a voluntary EPA / DOE recognition program, the Federal government may share in the cost of developing such tools.

There was some preliminary interest by private companies like Johnson Controls to utilize the benchmarking tool as a customer service or as a measurement and verification tool in performance contracting.

2.4.8 Recommendations

Based on the work to date, a 2- to 3-year effort funded at $75 to $100,000 per year is required to develop and test a robust benchmarking tool and public domain database.

The next steps would include:

- Refinement of the tool including addressing process and oversizing issues as well as improvements in the fan load model

- Debugging
- User testing
- Independent engineering review of calculations
- Overall user interface enhancements including a help function
- Web-based implementation
- Integration with the design intent tool for best practice and as-designed data.

2.5 Laboratory Design Guide

Goal

Provide a compendium of information on energy efficient laboratory design.

2.5.1 Introduction

No up-to-date comprehensive source of information on energy efficient design of laboratories was available. Such a resource was desperately needed by laboratory owners, designers, and operators to improve energy performance. Optimum design of laboratory facilities will result in 30 to 50 percent energy savings using available and proven technology.

2.5.2 Summary of Past Work

Significant opportunities for improved efficiency in laboratory type facilities are available but underutilized. To address this issue LBNL developed an energy Design Guide for research laboratories. LBNL continues this technology transfer activity.

Past work included:

- Produced an electronic version of the Design Guide. This guide includes cross referencing using an electronic hypertext format. The first electronic version of the guide included over 1,600 hypertext jumps for assisting the reader in finding related topics within the guide. LBNL implemented an “answer wizard” (free text searching using plain English) and a version that will self install in the Windows 95/98 environments. Disk copies of the electronic guide are available, however, users are encouraged to use the World Wide Web to access the latest version.
- The guide was used in tech transfer activities with ASHRAE, UC and California State University facility and energy managers, and two EPA and DOE/FEMP sponsored 3-day workshops.
- Published the hypertext electronic Design Guide on the World Wide Web. As in the disk version, the Web-based guide is formatted like a Help File and includes hypertext jumps for assisting the user in finding related topics within the guide. User feedback has been very positive.
- Provided ongoing improvement of the Design Guide. Based on input from industry and the Project Advisory Committee (PAC), LBNL made appropriate minor revisions. Edits based on comments and typos have been made. The Web version is maintained as the “current” version.

- Integrated the Air Flow Design Guide. The design guide was expanded when the Air Flow Design Guide was added to the section on air distribution. Dr. Robert Tsal, the principal author provided a broad range of information, from fundamentals to complex considerations such as duct system effects. Included are fundamental reviews of low velocity duct design, ductwork layout, air leakage, construction, materials, and fittings. Advanced design elements of pressure balancing, sizing, simulation, and information on optimization for California are also provided.
- Validation of the Design Guide was initiated on a real world lab design project to determine its benefits and seek owner and A/E fee-back to improve usefulness. A small elementary science institute in San Diego was selected for the validation. The test will span the entire design process. Through a series of telephone calls and a face-to-face meeting with the architects, Westberg + White Architects, valuable information was obtained to validate and provide feedback on the Design Guide. Results to date, involving both the non-technical owner and the architect in the project planning phase, were reported previously.

2.5.3 Project Objectives

This year's project objectives were to:

- Continue to support the electronic Energy Efficient Laboratory Design Guide – maintain the Web version, distribute floppy disks, continuously evaluate the Guide based on industry feedback, and make appropriate revisions.
- Continue case study of Guide's use on a new California laboratory.

2.5.4 Approach

Geoffrey Bell of LBNL is the lead author of the Design Guide [(510) 486-4626].

2.5.5 Project Outcomes

The following work was accomplished relative to the objectives:

- Continued support of the electronic Energy Efficient Laboratory Design Guide – maintained a Web version, distributed floppy disks, continuously evaluated Guide and made appropriate revisions.
- Continued case study of Guide's use on a new California laboratory and initiated second case study at UC Santa Cruz.

LBNL continued to expand and enhance the electronic Design Guide based on new information and ongoing input from industry. The Web version is maintained as the "current" version. The downloadable version of the guide was updated relative to the search engine's license. Integration of the Design Guide with the emerging Design Intent Documentation Tool (see separate task) has progressed. In addition to other minor revisions to "maintain" the Web version of the design guide, several enhancements were added:

- Created a "fill-in form" to track Web site visitors. Filling in a form will be required of anyone who wants to download the electronic version of the Design Guide. A database of these people provides a listing of potential attendees to future workshops and other technology transfer activities, as well as a list of users for notification of Guide revisions and updates. Information on users was captured for a mailing list for the Laboratories for the 21st Century conference in Boston.

- Adding a "search function" feature to the Design Guide's Web site. The electronic version of the Design Guide includes a help wizard by Answer Works™. However, a Web-based help wizard is not yet available. In the interim, a straightforward search feature that returns topic headings for desired terms was added to the Guide's Web site. This feature will work like a "find" feature in many help systems.

- Developing Web site "links" related to the Design Guide. A set of links relevant to the Design Guide has been compiled based on the topic structure of the Guide's ten chapters. To heighten the user's interface with these links, logos and graphics for each link are included in the link list. When necessary, a short description of the Web site referenced will also be included with a link.

2.5.6 Technology Transfer

The Laboratory Design Guide, available live or for downloading from the Web, remains a major technology transfer activity. We are now tracking the recipients of the guide (via a form required prior to downloading) and successfully used this information for a mailing list for the Laboratories for the 21st Century. Significant efforts have been made to make the guide known and easily available. It has been used as the foundation for several seminars and workshops including workshops sponsored by ASHRAE, EPA, DOE and UC/CSU.

A third Laboratory for the 21st Century conference was held September 8-10 with EPA and DOE/FEMP sponsorship. Over 200 people attended this highly focused conference in Boston and the Design Guide was distributed and used to build a foundation of knowledge. In addition, we provided training based on the Design Guide at the Sandia National Lab in May. This activity was DOE funded and involved students from UNM as well as Sandia staff.

We have realized some success in getting the Design Guide accepted by California Universities. For example, UC Santa Cruz specified its use in a recent design program, and used it in a value engineering exercise. We have also been successful in getting the entire California State University System to consider adopting the Design Guide as their state-wide reference for energy-efficient laboratory construction and retrofits.

2.5.7 Conclusions

The Design Guide has been extremely well received by users (owners, builders, designers, and operators), however, it is most successful with energy zealots – the type that will come to an energy efficiency workshop or search the internet on this topic. We have worked to get the Design Guide referenced in design contracts and design programs.

The advantages of using the Design Guide combined with the Design Intent Tool in a project's planning phase were apparent in our validation case study. Further, the application of the Design Intent Tool encourages use of the Design Guide. However, during our validation task, it became quite clear that a more refined and seamless linkage between the Design Intent Tool and the Design Guide is very important. Likewise, informal feedback from users and potential users of the Guide indicated that more structure is needed for greater utilization. Only the most zealous of designers will thoroughly read a 400+ page reference, even if its use has been specified in their contract (usually with dozens of other references). Therefore, we took advantage of the Design Intent Tool's structure and the synergy between the two products, and electronically linked the Guide with the Tool. Owners that specify use of the design intent documentation tool (when available) will therefore have greater assurance that the Design Guide is used and energy efficiency will be realized. The energy performance methods and expectations will be explicitly documented as opposed to broadly promised (most designers claim to provide energy efficient products). The Design Intent Tool will provide "structure" for the use of the Design Guide, and thus increase the use and effectiveness of both.

Profit from the development and sale of a laboratory design guide for energy efficiency is unlikely. This is a public goods activity. Future funding to enhance the Design Guide (see Assessment of future research needs) has not been identified.

2.5.8 Recommendations

Proposed enhancements of the Design Guide include:

- Improve integration of the Design Guide with the Design Intent Documentation Tool.
- Provide an editorial page in the Design Guide Web site. This will furnish a periodic review of pertinent articles and publications and create an incentive for visitors to bookmark the Design Guide's Web site and return on a regular basis. In addition, if there is enough interest in a topic, a threaded discussion could be formed.
- Add a Power Point™ demonstration / tour of the Design Guide at the Web site to provide a user-friendly overview of the content and organization.
- Increase graphical content.
- A major update of the Design Guide is due. This would involve a new and deliberate literature search to capture recent laboratory energy efficiency information, a substantial increase in the use of Web links, a thorough review of the Design Guide for accuracy and clarity, and a review of the user interface.

2.6 Clean Room Benchmarks

Goal

Improve energy efficiency and performance of clean rooms through benchmarking across industries.

2.6.1 Introduction

Clean room owners and operators know that their energy costs are high, often their highest operating cost, however they have little way of knowing if they are good or bad. Most assume that their energy costs are a fixed cost (not subject to reduction). The goal of developing clean room benchmarks is to provide owners and operators with a measure of performance. These facilities are extremely complex with energy consumption often driven by process or non-building loads. The variety of industries utilizing clean rooms coupled with the lack of installed metering makes benchmarking of the clean room, without the effects of the process within the room, very difficult. Therefore, simple metrics such as energy or cost per square foot are useful only in comparing like processes in similar rooms. The goal is to identify and collect benchmark data that can be used across industries that utilize clean room facilities. Clean room benchmarks will allow the industry to identify best practices and to establish individual performance goals.

The economic goal is to give clean room owners and operators better information to understand where the key energy drivers are, and take steps to improve energy efficiency in their facilities improving their economic competitiveness. It is also possible that improved clean room benchmarking techniques will facilitate energy performance contracting for these types of facilities. If clean room benchmark data leads to a 10 percent energy savings, 224 kW, and 940 million kWh will be saved in California yearly.

2.6.2 Summary of Past Work

Past benchmarking work has focused on three activities:

1. Collect Existing Monitored Data: Collecting existing data was the first step in establishing a database of clean room energy performance. Unfortunately, little data was available, partially due to the proprietary nature of most clean rooms. LBNL has established a relationship with Supersymmetry Services, headed by Lee Eng Lock, one of the world's leading experts on clean room HVAC, to assist us in gathering and analyzing existing data on clean room energy performance. LBNL has identified existing data sources such as Sematech's current pilot energy audit study of semiconductor fabs, Sandia laboratory's clean room facilities, EPA sponsored audits, and other industry sources. With this data LBNL was able to assess the current state of knowledge on actual clean room energy performance and identify key gaps to be filled in future monitoring efforts.

   Supersymmetry obtained a contract to perform an energy audit / study of a major (150,000 square feet $1.7 million annual energy cost) clean room at Sandia National Laboratory (Albuquerque, New Mexico). Sandia's energy manager, Ralph Wrons, was willing to share results since a National Laboratory has less proprietary issues than many private sector case studies.
2. Case Studies: In conjunction with collecting existing data, LBNL developed case studies of best practice with wide applicability to California clean rooms.
3. Develop Benchmarking Metrics: No industry standard metrics for comparing the energy performance of clean rooms exists. In conjunction with the monitored data collection effort, LBNL and Supersymmetry developed a preliminary set of clean room metrics that account for key drivers of energy use and demand.

2.6.3 Project Objectives

This year's project objectives included:

- Continue benchmarking work, including collection of most recent monitored data, refinement of metrics, and expansion of case studies.
- Disseminate case studies on LBNL's clean room Web site.

2.6.4 Approach

The LBNL lead researcher on the benchmarking task is Bill Tschudi [(510) 495-2417]. He is supported by Energy Analyst Dr. John Busch, and by Supersymmetry. Industrial partners also make in-kind contributions.

2.6.5 Project Outcomes

This year resulted in the following outcomes:

- Continued benchmarking work, including, refinement of metrics, and expansion of case studies.
- Arrangements have been made with PG&E to begin a major data collection effort in FY2000.
- Disseminated case studies on LBNL's clean room Web site.

LBNL and Supersymmetry, continued to gather existing data from a wide range of facilities. The current state of energy efficiency implementation has revealed the following impediments. First, on a positive note, some of the largest firms operating clean rooms in California have begun to examine their energy use practices. A number of benchmarking efforts undertaken by individual companies and a benchmarking effort by Sematech have provided valuable information to the participating firms. LBNL attempted to obtain the benchmark data prepared by Sematech for fourteen semiconductor manufacturing facilities (fabs) worldwide. Unfortunately this information is being treated as confidential to the member companies of Sematech. Many firms are reluctant to share the findings for two reasons. They are concerned that regulators may use raw benchmark values and limit their ability to maximize use of their facility, and there is a proprietary concern that their competition would gain knowledge of their processes or manufacturing practices. Many firms have yet to perform any benchmarking, and indeed may not have adequate instrumentation in their facility to gather the necessary data. Data from an EPA sponsored study of a major semiconductor manufacturer, and projects conducted by Supersymmetry was obtained.

In conjunction with collecting existing data, LBNL developed case studies of best practice with wide applicability to California clean rooms. Five case studies were completed and are included in the Appendix and on our clean rooms Web page http://eetd.lbl.gov/cleanrooms/:

- Applied Materials – Chilled Water Plant Efficiency Upgrade
- Genentech – New Energy Efficient Pharmaceutical Manufacturing Facility
- Hine Design – Variable Speed Drive Control of Recirculation Fans for Class 100 Clean Room
- Motorola – Clean Room Declassification from Class 10,000 to Class 100,000
- Western Digital – Comprehensive Clean Room Facility Renovation and Cleanliness Upgrade.

The case studies were quite varied and demonstrate a whole systems approach as well as stand alone improvements in various areas. These case studies were featured (presented) at an industry workshop on March 15, 1999. Permission to publish the case study of another comprehensive project for SG Thomson was denied after effort to develop a report was expended, therefore it is not able to be included in the project documentation.

Development of metrics that account for key drivers of energy use and demand continued to be refined. Factors considered include cleanliness levels, production levels, weather, facility size, code classification, and others. Future activity will seek to get industry representatives to agree on standard metrics for comparing the energy performance of clean rooms.

With this situation, LBNL advanced this issue by preparing a list of parameters, which are most worthwhile to measure, and their associated measurement units. This will provide a framework for building owners to consider further benchmarking, leading to energy efficiency improvements. The parameter list will be made available to industry through market transformation activities with the goal of convincing facility operators that sharing best practices is in their best interest. The metrics document identifies suggested metrics to be used and has provisions for recording best practice information as we are able to identify them.

2.6.6 Technology Transfer

We intend to work with California utilities, primarily PG&E, and possibly SDG&E, under market transformation programs to define, collect, and report clean room benchmark data utilizing metrics developed under this task. This activity will draw heavily on the research conducted in this project.

2.6.7 Conclusions

Due to the lack of existing data, and the reluctance of many operators of high tech buildings to share data, we shifted emphasis in this activity towards establishing key benchmark criteria which would provide for immediate benefit to building owners even if they were reluctant to share data publicly. The original goal assumed that data existed and would be readily available. Our findings are that little data existed and that which was collected was frequently treated as confidential information. Interest in benchmarking appears to be growing, however, and further definition of metrics as well as comparative data should be obtainable through other public interest benchmarking activity.

Almost all industry participants agree that clean room benchmarking is valuable, however there is little commercialization potential of selling such information. Sematech, an organization of semiconductor manufacturers, has developed benchmark data, however they are using metrics unique to their industry (i.e., energy per square inch of silicon wafer). Further, they consider the information proprietary to their members (large semiconductor manufacturers), so it is not available to most clean room owners and operators. This position is taken for competitive reasons, and for fear of regulation. Therefore, clean room benchmarking will likely remain an internal industrial activity or will require Public Interest activity to make useful data accessible to the majority of clean room operators in high tech manufacturing.

2.6.8 Recommendations

Other research in this area should include an assessment of various metering and data acquisition options for efficiently acquiring benchmark data and providing analysis or trending information. Once benchmarking data has been collected, further analysis of the data may reveal additional research needs including the need to refine the performance metrics and reporting mechanisms.

2.7 Clean Room Analysis Tools

Goal

Develop HVAC energy analysis and design tools for clean rooms.

2.7.1 Introduction

A critical need was thought to exist to develop analysis tools that would facilitate a systems-oriented approach to design of clean room facilities. Industrial clean room design firms were thought to employ in-house proprietary analysis techniques for sizing and perhaps predicting operating performance of their designs. Existing publicly available energy analysis and design tools (such as DOE-2) are made for more conventional commercial and residential buildings. The applicability of these publicly available models for assessing the energy performance of specialized industrial and laboratory type facilities, such as clean rooms with high airflows, strict environmental requirements, multiple fan systems, and varying process loads, was unclear. LBNL has scoped the limitations of existing tools and clarified the needs for energy design and analysis tools for clean room facilities. This task provided the groundwork for future work, enhancing existing or developing new energy design and analysis tools for clean rooms.

The economic goal of this task is to provide energy savings by identifying or developing tools capable of assisting designers in assessing energy use, and enabling design of energy efficient clean room systems. It is possible to achieve energy savings of 10 to 50 percent if energy use was modeled and analyzed effectively.

2.7.2 Summary of Past Work

LBNL demonstrated the potential performance of the clean room of the future by developing a case study model of a typical microelectronics fabrication clean room based on current practice. Using this model LBNL conducted an illustrative study to quantify the energy savings possible with an integrated design. A building description of a "typical" fabrication ("fab") facility was developed and reviewed by several industry experts. A simplified DOE-2 model was developed based on this building description. A revised description and model of the fab was developed to illustrate the opportunity for energy efficiency. The analysis was completed and the results were presented to an industry group at a workshop sponsored by EPA. See Figure 15.

2.7.3 Project Objective

The project objective for this year was to continue evaluation of clean room analysis tool needs and the potential enhancements to an existing computer-based energy analysis tool (potentially DOE-2.2).

2.7.4 Approach

This task was performed by LBNL with John Busch as the lead investigator [(510) 486-7279]. Bill Tschudi interfaced with industry design firms.

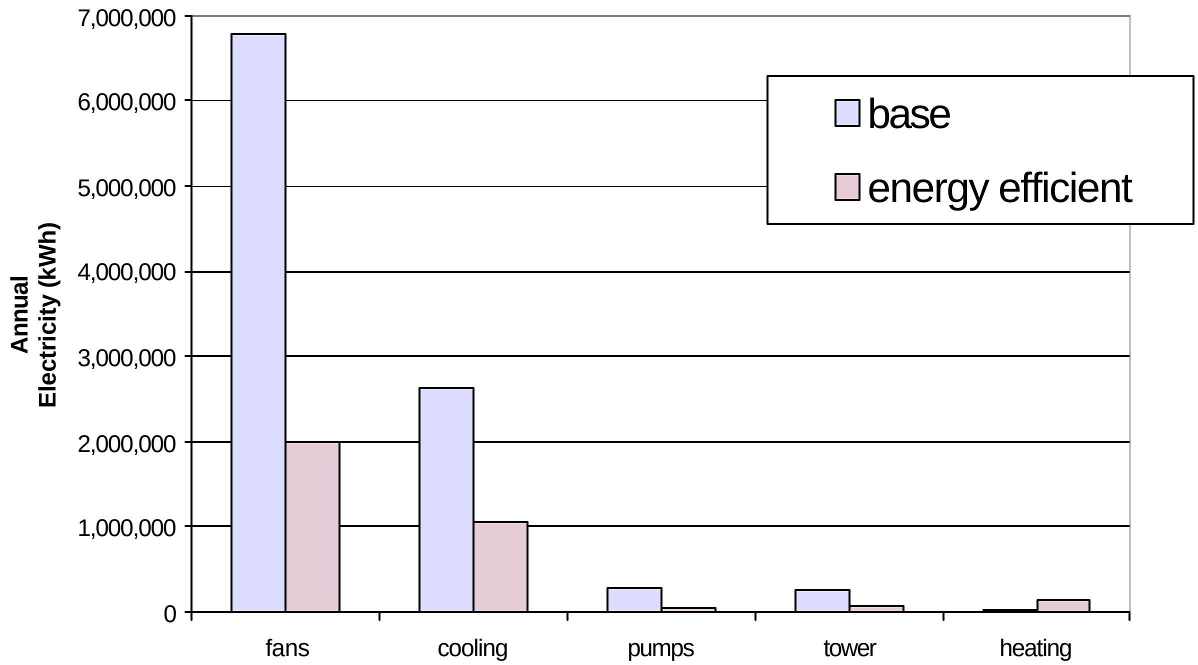

Figure 15. Energy Savings Potential in Typical Clean Room

2.7.5 Project Outcomes

The outcomes accomplished this year include:

- Continued evaluation of clean room analysis tool needs and the potential enhancements to an existing computer-based energy analysis tool (potentially DOE-2.2)
- Determined that although a technical need exists, designers are satisfied with their existing tools and have little incentive at the present to change.

LBNL conducted a survey of leading designers of clean room facilities to investigate current practices. The survey was intended to determine the adequacy of design and analysis tools currently in use and asked the respondents to identify the tools they use and their applicability to clean room design. Through a series of questions we sought to identify features that needed improvement or other enhancements that they would like to see. LBNL has compiled the results of the survey and they are presented in the Appendix.

The results of the survey indicate that the existing computer programs and models may not adequately handle the clean room design problem, however, designers feel existing tools are adequate for the level of accuracy needed in their work (primarily for sizing). Generally, the responses indicated that energy analysis is a low priority for clean room designers. The designers surveyed do not see a need to enhance existing analysis programs. They typically use analysis programs such as DOE2 for the more conventional portions of the facility, and utilize spreadsheet programs to design the clean room specific systems. Currently, owners do not require a detailed energy accounting, so designers are not interested in providing it. In addition, many designers mentioned the fact that the design heat load due to process considerations is frequently over estimated by the owners by as much as a factor of two. Thus more refined energy analysis would be meaningless compared to the magnitude of deviation in the base assumptions. Therefore, any effort to improve the tools would require a significant market transformation activity to assure that the energy analysis tools are used and that other oversimplifications are corrected.

2.7.6 Technology Transfer

No further activities are planned at this time. Development of Energy Plus continues through other funding sources however, and modifications to accommodate clean room design may be facilitated in the future.

2.7.7 Conclusions

The results of the survey of design firms experienced in clean room design indicated that energy analysis tool improvement was not a priority for this group. The task was successful in developing an understanding of the limitations of the existing analysis tools, the design community's use of the tools, and identification of options in developing new analysis tools. Four potential paths are identified. The fact that other issues, such as estimates of the process heat loads, are far more uncertain, lead to a conclusion that development of more refined energy analysis tools at this time is premature.

As described in the report of this investigation (see Appendix), Energy Plus is a program that could be revised to compensate for the DOE2 program shortcomings. In addition, the VisualSPARK program, with some development could be made to accurately model a clean room configuration. This development would require a significant commitment that at present time does not appear to have a strong industry interest.

2.7.8 Recommendations

Development of more accurate and user-friendly clean room energy analysis tools need not be a high priority. As the clean room industry becomes more aware of energy efficiency options, and as competitive pressures cause owners to more aggressively demand efficient design (or at least know where their facility falls in the range of energy use), the need for better energy analysis tools may increase. Until facility managers begin to ask for efficiency measures and require meaningful energy analysis as part of the design process, the need for advanced clean room energy analysis tools is low.

2.8 Clean Room Technology Transfer and Industry Liaison

Goal

Form collaborative alliances with industry organizations to assure success in the marketplace.

2.8.1 Introduction

The principal goal of this activity is to develop industry alliances and input to enrich the research agenda and tech transfer. Through a series of meetings, conversations, and surveys current practices and needs were assessed. This information was then to be used to develop strategies and research topics to address the most critical energy efficiency needs.

This task helps to achieve the overall program economic goals through increased awareness and through coordinated research efforts.

2.8.2 Summary of Past Work

LBNL established an energy efficient clean room Web site on the Internet. This site is targeted to facility designers, operators, and financial decision-makers. The Web site serves as an information resource to overcome institutional and technical barriers to energy efficiency in clean rooms. The Web site features a comprehensive annotated bibliography of literature on energy efficiency in clean rooms, links to other related Web sites, fact sheets, and LBNL publications in this area. LBNL will continue to expand the site with content derived from other tasks. See Figure 16, and visit the clean room Web site at: http://eetd.lbl.gov/cleanrooms.

Figure 16. Web Site for Efficient Clean Rooms

Other Related Activity

Other related activities included:

- UC SMART: The University of California has established a collaborative grant program with the semiconductor industry called the Semiconductor Manufacturing Research and Training (UC SMART) program. This program provides support in the form of matching grants for research and fellowships for graduate students in areas of mutual interest to semiconductor industry companies. LBNL pursued contacts with one of the leading producers of chip manufacturing tools, Applied Materials, as a possible co-sponsor of research on resource efficient semiconductor manufacturing. LBNL clean room staff and Applied Materials executives held a series of meetings at each other's sites. While a UC-SMART proposal was not developed for the first round with Applied Materials, LBNL staff worked with a UCB graduate student in the Energy and Resources Group and faculty member Cathy Koshland to submit a fellowship proposal to UC-SMART.

- Applied Materials: Several meetings were held with Applied Materials, the leading supplier of manufacturing tools to the semiconductor industry, to discuss collaboration opportunities. Applied Materials is interested in several LBNL technologies and discussions continue. Also see above description of UC SMART.
- AeroVironment and Envirco (Fan Filter Unit): The processes undertaken within clean rooms, and the demands placed on most production clean room facilities change rapidly. Based on attendance at trade shows and contacts with industry (including an EPA funded workshop) we have determined a major trend towards the use of "fan filter units." These modular units which fit into and cover all or a large portion of the ceiling replace large central air handlers and filter units. Initially industry experts felt these units would only be used in small clean room facilities, however the trend is towards widespread use in facilities of all sizes. The primary benefits to these units are speed of design and construction. Secondary benefits include redundancy and flexibility. A major disadvantage is reduced energy efficiency. A good analogy in commercial buildings is the use of roof top units (inefficient but widely used). We feel there is a major product development opportunity to enhance the performance of these units, and we have initiated discussions with potential manufacturers (motor, fan, filter, and unit manufacturers). One fan filter manufacturer (Envirco) claims a 40 percent market share and was receptive to discussing collaboration on a high efficiency model. We begun to tabulate fan-filter manufacturers' information in anticipation of eventual research in this area.
- Arkwright: Arkwright Mutual is a major insurer of clean room manufacturing facilities. Although Arkwright does not see a major connection between energy efficiency and loss prevention, they market based on providing high engineering value (beyond insurance products) to their customers. For example they own Factory Mutual (more widely known for its engineering support and certification). Preliminary discussions with Arkwright have focused on benchmarking activity – they currently provide clean room performance benchmarks not relating to energy.
- Progressive Technology (Exhaust Valve/Air Control): Progressive Technology manufactures an innovative exhaust valve/air control technology that generated excitement at the EPA sponsored workshop on energy efficiency in semiconductor manufacturing held in San Jose in Fall 97. Their technology has the potential to significantly reduce the makeup air requirements that form a significant share of HVAC energy use in clean rooms.
- Center for Environmental Benign Semiconductor Manufacturing: Ashok Gadgil, an LBNL scientist was part of panel discussion, along with Amory Lovins, Phyllis Pei of Sematech, Roger Mora of Applied Materials, and Lee Eng Lock of Supersymmetry at the annual meeting of the Center for Environmentally Benign Semiconductor Manufacturing held at Stanford University in August 1998. Dr. Gadgil presented LBNL work on energy efficient clean rooms.

2.8.3 Project Objectives

This year's project objectives for this task were to:

- Host and document a clean room design charrette.
- Attend and participate in clean room industry forums to transfer knowledge, expand network, and build industrial relationships.

2.8.4 Approach

This work is being done at LBNL under the leadership of Bill Tschudi [(510) 495-2417].

2.8.5 Project Outcomes

Our project outcomes this year included:

- Hosted a clean room workshop and published the proceedings which were distributed to all attendees.
- Hosted two clean room design charrettes, one with Genentech and one with a major San Jose electronics company.
- Attended and participated in numerous clean room industry forums to transfer knowledge, expand network, and build industrial relationships.

LBNL hosted a workshop on energy efficiency in California clean rooms. In preparation for the workshop, LBNL contacted key industry organizations and companies and developed a network of regional industry contacts. The workshop was attended by close to 50 people, representing leading California firms in the semiconductor and biotechnology industries, as well as national laboratories, semiconductor equipment manufacturers, engineering firms, and research organizations. See Appendix for a partial copy of the workshop proceedings.

LBNL issued a solicitation for a project to perform an energy design charrette. We appealed to a broad cross-section of firms in seeking a clean room design project for either a new facility or a retrofit of an existing facility. Our criteria for selection included that the project would be located in California and would be complex enough to allow for a number of energy saving ideas to be explored. A biotechnology clean room project was identified with Genentech. LBNL also arranged for a second design charrette with a major electronics firm in Silicon Valley. These design charrettes involved key designers, owner/builders, and energy experts. The intent was to elicit integrated solutions from a variety of disciplines and perspectives. See Appendix for the design charrette reports.

The LBNL clean rooms work is being coordinated with other related work at LBNL and elsewhere. LBNL coordinated with the Northwest Energy Efficiency Alliance, Sematech, EPRI, EPA, ASHRAE, and other industry efforts. LBNL staff have formed alliances with these groups and others interested in clean room energy efficiency, and participated in a number of meetings to collaborate on advancing clean room technology and performance.

Other Clean Room Technology Transfer Activity

Other clean room technology transfer activities included:

- Northwest Energy Efficiency Alliance (NEEA): LBNL attended a workshop hosted by the Northwest Energy Efficiency Alliance in January. This led to some key industry contacts with the Semiconductor industry and an invitation to attend Sematech's Energy planning meeting in Austin, Texas. Collaboration with this industry is extremely critical to advancing energy efficiency issues in California clean rooms. The NEEA workshop focused on benchmarking and was very instructive in revealing concerns that the industry has on release of information. Three NEEA staff and Chris Robertson, their prime contractor, attended our clean rooms workshop. Chris also met with us to follow-up on regional collaboration issues and opportunities.
- Sematech: LBNL was invited to attend a Sematech energy-planning meeting in Austin, TX. In this meeting the Sematech FY99 energy research agenda was discussed. Key Sematech member companies were represented, so it provided an excellent opportunity for industry networking and the exchange of ideas. One staff person and several Sematech member companies attended our workshop. Since these meetings, discussions have ensued regarding greater collaboration, however, the proprietary nature of Sematech's work remains an issue.
- ATMI: ATMI, a supplier to the semiconductor industry, has signed an option agreement with LBNL to develop our containment technology (see ultra low flow fume hood project description above). ATMI will work on applications in the semiconductor industry. The agreement was announced to industry at the workshop on March 15th.
- Motorola: Phil Naughton, a senior engineer, and long time efficiency advocate at Motorola attended the clean rooms workshop. He was invited to meet to share insights on barriers and opportunities relative to the cleanest and most energy intensive of clean rooms. He described Motorola's energy management activity which was very modest given the opportunity (he devotes a fraction of his time to manage a $30 million energy budget).
- EPRI: LBNL had several meetings and extensive conversations with EPRI to identify collaboration opportunities. EPRI was represented at our clean rooms workshop.
- ASHRAE: LBNL participated in the ASHRAE annual meeting and attended a number of seminars and forums concerning laboratory and clean room issues. Based upon this meeting, contacts for future collaboration were established with the ASHRAE clean room committee. LBNL will participate as a corresponding member to the clean room technical committee.

2.8.6 Conclusions

This year's technology transfer and industry liaison activity underlined the significant opportunity that exists for energy efficiency in clean rooms, and the fact that this market has been under-served by prior demand side management and energy efficiency R&D programs. Gary Shoenhouse from Genentech commented in his presentation at the clean rooms workshop that he didn't know so many people in the country were interested in clean room efficiency opportunities. Many of the attendees voiced praise for the opportunity to network with peers and learn about opportunities specific to their industry and building type. A significant market transformation need exists.

The industry liaison activity was very successful in connecting with a broad cross section of individuals representing many of the industries with high tech facilities. The stage has been set for collaboration with industry associations such as Sematech, SEMI/Sematech, IDEMA, ASHRAE, and the Major Energy User Group (MEUG). These organizations are instrumental in setting energy policy goals and are extremely interested in research performed by LBNL for high tech buildings.

LBNL has established relationships with some of these organizations and is beginning to coordinate research activities. LBNL has also established numerous industry contacts that are a rich source of research needs and priorities. In some cases, industry has begun to sponsor research building upon LBNL's research. For example ATMI is applying our new "air dam" technology to the semiconductor industry. In other cases, it is useful to coordinate with industry's innovations and leverage their efforts to even greater applications.

LBNL will also be providing technical guidance to the DOE Federal Energy Management Program for high tech federal facilities. An Executive Order was issued which severely limits the previous exemption for implementing energy efficiency improvements in Federal facilities. In response to this order, LBNL will participate in determining appropriate exemption criteria for high tech buildings, and will provide design assistance for specific projects.

2.8.7 Recommendations

There is a broad need for technology transfer and outreach to the various industries that operate clean rooms. A number of organizations recognize this need and plan to continue technology transfer activities. The Northwest Energy Efficiency Alliance is interested in applying all relevant research to their Northwest high tech firms and has offered partial funding for a future activity to develop a clean room programming guide. PG&E is sponsoring LBNL to perform benchmarking of clean rooms which should provide a valuable database of performance data, as well as a field test of the ultra low flow fume hood. This activity will likely lead to identification of priority research and development needs.

Industry liaison will continue to be an important activity under this program. In particular, the industry associations important to the high tech sector will play a major role in defining future R&D needs and in some cases will need to endorse innovative technology before it is implemented and/or accepted by industry. These organizations include Sematech, ASHRAE, SEMI/Sematech, IEST, IDEMA, and others.

3.0 Overall Technology Transfer

See individual task report sections above.

Numerous presentations were made this year covering the project as a whole. These included presentations to the Major Energy Users Group (MEUG), the Association of Energy Engineers (AEE), and the EPA / DOE Laboratories for the 21st Century Conference (Boston). A sample MS Power Point presentation is included in the Appendix.

Several articles were written about the project. Articles were included in our division Newsletters widely circulated to the public and industry, as well as the internal LBNL newspaper (Currents – April 23, 1999). A more specific article on the opportunities for energy efficiency in clean rooms was published in Clean Rooms magazine. Several of these articles are included in the Appendix.

Four project participants had a significant role in the EPA and DOE sponsored Laboratories for the 21st Century conference (only one was paid for from this project). We participated on the planning team, made seven different presentations, and led two panels. The electronic Design Guide was distributed and played a major role in the conference. California's leadership and role in developing energy efficient technologies for laboratories was clearly demonstrated. See the Appendix for further information on the conference.

We also participated in relevant committee meetings (laboratory and clean room) at the summer ASHRAE meeting in Seattle.

Given the role of Utilities in the emerging California market transformation activities, we initiated several meetings with PG&E to discuss this target market and the integration of R&D and market transformation activities. PG&E has identified micro-electronics and biotechnology among their largest and fastest growing industrial sectors. Based on a recommendation from the Energy Commission, we contacted the PG&E Food Services Center. They have significant R&D and market transformation programs related to kitchen hoods and ventilation in the food services industry. We discovered several areas for potential collaboration.

3.1 Relevant Web Sites

Laboratories for the 21st Century is emerging as the preeminent national conference on sustainable laboratory design. LBNL was on the organizing team and was a major participant. The agenda and many of the presentations can be viewed at: www.epa.gov/labs21century.

One tool that we developed that has been popular is a Design Guide for Energy Efficient Laboratories. This electronic document is set up in a help file format and can be used on the Web or down loaded from: http://ateam.lbl.gov/Design-Guide.

The California Institute for Energy Efficiency has funded much of our recent work. Their Web site on Clean Rooms and Laboratories for the Electronics, Biotechnology, Pharmaceutical, and Other High-Technology Industries, highlights the opportunity and several aspects of the project: http://eetd.lbl.gov/CIEE/Sartor1998.

One area of particularly great opportunity is energy efficiency in clean rooms. We have established a Web-site to be used as a clearinghouse for information and case studies: http://eetd.lbl.gov/cleanrooms.

As cooling is often a major load in high tech buildings, this site focuses on integrating system and building (load) efficiency with CFC chiller replacement/retrofit projects: http://ateam.lbl.gov/COOLSENSE/coolsense.html.

The Applications Team at LBNL is a joint venture between our facilities department and our building energy researchers. The A-Team Web site has links to the Design Guide and the Clean Room site, as well as links to Cool$ense, FEMP and other Web sites: http://ateam.lbl.gov.

Several summer students participated in a Student Mentor program in 1999. A special Web site describes their activity: http://ateam.lbl.gov/students.htm.

4.0 Public Interest RD&D Implications

As documented in the LBNL market update from July 1999, a rigorous energy efficiency program serving laboratories and clean rooms has the potential to save 40 to 50 percent of the current 9.4 billion kWh of electrical power consumption for these industrial buildings. If pursued, this would begin to decrease the energy consumed and avoid a significant amount of new power generation resulting in significant environmental emissions reduction and conservation of natural resources. It would also have a direct economic effect by improving the profitability and viability of California industries thereby keeping high tech industry in California and providing for job retention or growth.

A challenge in working with many laboratory and clean room owner/operators is the confidentiality surrounding their operation. Potential collaborators, whose research is germane to our own, are reluctant or unable to share information citing confidentiality issues. Some larger firms are beginning to address energy issues with in-house staff, however while this is a positive step, it often results in sporadic results not benefiting the industry as a whole. Public goods research and development is needed to achieve widespread sustainable improvement. This is especially important for the less sophisticated "second tier" companies that can't afford access to proprietary research, nor conduct their own, but are perhaps most sensitive to energy costs which is often their highest operating cost.

Specific RD&D task implications:

- Use of the Design Intent tool will enable building owners and designers to focus on key energy saving features and follow their use through the building life cycle. It will facilitate continuous improvement leading to further energy savings.
- Use of the low flow fume hood will reduce exhaust by up to 70 percent, saving energy for conditioning make-up air and reducing the size of ventilation systems. In addition to significant energy savings (2.3 kW and 8.5 MWh/year per hood), and reduced first cost (new construction), low flow fume hood technology will improve containment and user safety.
- Airflow Design tools if fully developed will permit systems to be sized optimally, improving equipment efficiency and reducing the size of HVAC systems. Optimum designs will consider life cycle cost and will result in quieter and safer airflow systems.
- Use of the Laboratory Design Guide will assist in saving 40 to 50 percent of energy in laboratories both in new construction and retrofit. Application of the Laboratory Design Guide can reduce energy, improve worker safety, environmental conditions (e.g., lighting, temperature control, air quality, and noise), productivity, and reliability.
- Assuming that clean room benchmark data leads to a 10 percent energy savings, 224 kW, and 940 kWh per year will be saved in California. Public goods activity will be especially important to the smaller "second tier" manufacturers and researchers. This benefit is extremely important to manufacturers of more "commodity" type products such as disk drives, that are much more cost sensitive than the major manufacturers or manufacturers of unique products.

- Participation in Technology transfer and Industry Liaison activities is extremely important to California industry. California has the largest concentration of laboratory and Clean Room facilities in the country. By collaborating with other industry activities and research, California can remain competitive and not lose industry to other geographical areas.

Many of the technologies developed for buildings for high tech industries have relevance to other building types. So the potential energy efficiency improvement goes far beyond laboratories and clean rooms.

To summarize the benefits:

- Reduction in energy use of up to 50 percent
- Avoidance of power generation of up to 4.7 billion kWh
- Emissions reduction
- Conservation of natural resources
- Retention of Industry in California
- Job growth
- Improved efficiency in other building types
- Improved worker safety.

5.0 Overall Assessment of Future Research Needs

5.1 Introduction

Research to date has reinforced that the opportunity for energy efficiency improvement is great for laboratory and clean room buildings for high tech industries. The research activities begun under this program should be taken to conclusion to begin to take advantage of efficiency opportunities (see individual task report sections above for specific recommendations). Our work has identified a number of additional strategies and technologies that are targets for future research. Our research plan addresses a multi-year approach building upon our research to date and the efforts of others.

Since many of the institutions and industries with high tech buildings are continually changing their research, processes, and products, there are frequent changes to the facilities which, in turn, generate opportunities to make improvements. In addition, the design and construction of new facilities is far from optimal. Construction of new laboratories and clean rooms is continuing at a rapid pace, with California leading the nation in the number of clean rooms. Elements of the LBNL research program plan are applicable to both retrofit and new construction in that the technologies ultimately target efficiency improvement in building systems.

Many industries and institutions utilize laboratories and clean rooms. These include semiconductor manufacturing, semiconductor suppliers, pharmaceutical, biotechnology, disk drive manufacturing, flat panel displays, automotive, aerospace, food, hospitals, medical devices, universities, and federal research facilities. Some of the larger firms with these types of facilities are interested in reducing energy consumption. Industry associations such as Sematech, ASHRAE, Major Energy Users Group (MEUG – in Silicon Valley), EPRI and the Northwest Energy Efficiency Alliance also are searching for areas for improvement. Many other organizations, however, have fewer resources to apply to energy efficiency, and could benefit from research, technology transfer, and innovative implementation schemes. What is needed is an integrated “roadmap” which maximizes and coordinates the efforts of various research and market transformation efforts, and guides a multi-year plan to transform these industries. Research and industry involvement is needed to identify and prioritize the areas of concentration.

This plan, or roadmap, would tie together present research, and identify key technologies and strategies to be pursued in future research. LBNL’s focus to date has been on the facility systems and will target improvements in process systems and equipment as a later priority. Several key areas for future research are clearly evident.

5.2 Continuation of Priority Tasks

The following research tasks performed by LBNL and its collaborators under this program are considered a high priority and should be taken to completion. Additional detail and recommendations are provided in the individual task reports above:

5.2.1 Laboratory Design Intent Tool

Initial testing and refinement of the design intent documentation tool is now appropriate.

5.2.2 Improved Containment Technology for Fume Hoods

Research and development through field demonstration and testing will be necessary before commercialization. This includes technical changes identified through testing, performance acceptance testing, and codes and standards work. This has some cost sharing from the U.S. DOE and Montana State University.

5.2.3 Air Flow Design Tool

Conversion of modeling algorithms into a software tool is the next step for this technology.

In previous phases analytical equations were developed. Developing a computer code to solve the complex equations is now a priority to realize the benefits of this prior research.

5.2.4 Laboratory Benchmarking

It is now appropriate to seek an initial (alpha) population of the database, followed by modeling refinements. Prior work has led to a promising concept to enable building owners, operators, and architect-engineers to gauge the efficiency of a building by comparing measured performance to a theoretical maximum efficiency. This technique will also allow comparisons to other buildings. The technique overcomes the difficulties of trying to compare dissimilar buildings by creating an ideal model of the facility and comparing its actual performance to the ideal.

5.2.5 Laboratory Design Guide

The Web-based design guide needs a major update and ongoing maintenance. New technologies and links to current information need to be established to keep the tool useful.

5.3 High Priority New Initiatives

Should the roadmap process be sponsored, the research plan would then be further developed to support the priority research tasks. The goal will be to align the efforts of industry, A/E's, Researchers, Utilities, and industry professional organizations to the extent possible. In this way, duplication of effort will be minimized and advances should occur in many areas simultaneously. LBNL proposes to work in partnership with Industry to develop the implementation plan for the needed technologies and programs. The exact content of these initiatives will be determined during the roadmapping. LBNL developed the following key focus areas to begin the dialogue.

5.3.1 Development of Roadmap

Planning, or developing a "roadmap," will provide a clear path for research and development direction. This will focus activities and direction for an overall program. The roadmap will provide for collaboration with other research efforts and facilitate research which is complimentary to others efforts. It will provide a forum for California industry to identify technologies and strategies that are needed to permanently transform the market. It will also provide a forum for suppliers to develop goods and services for new technologies. The roadmapping process will be able to assist in setting energy performance targets, and market transformation follow-on to achieve them.

5.3.2 Clean Room Programming Guide

This is a new activity that was identified as a high priority during the execution of the current project phase. An analog to the laboratory design guide is needed for clean room facilities, oriented toward the earlier phases of the building process (i.e. programming). Many design decisions are made at the programming phase and become irreversible as the design progresses. Therefore providing guidance at this phase is extremely important. Research will identify the areas, components, systems, and features most important to clean room energy use. This information will form the basis for a guide document which would be a resource for building owners and designers. Then a programming process which would be specific to the energy aspects of design will be developed. There is cost-sharing available for this development work from the Northwest Energy Efficiency Alliance (NEEA) with the provision of CEC involvement.

5.3.3 Design and Analysis Tools

Currently there is no accurate method for energy analysis within complex high tech buildings. Through use of a program such as DOE-2, an energy analysis tool specifically developed for use in complex, high tech buildings would allow designers to optimize energy use. Such a program could then be used to quickly determine the energy characteristics of various design options. It would more accurately account for the energy use in a complex laboratory or clean room facility. For more complex situations, an integrated CFD and HVAC system model could be developed to provide a powerful tool for clean room designers to optimize their design.

Understanding how air flows around equipment in clean rooms could also lead to better strategies for reducing airflow locally, thus saving energy and increasing cleanliness performance. A suggested task is to model commonly found shapes for various flow conditions using CFD modeling, and establish standard airflow guidelines for those cases.

Eventually it may be possible to build an energy model of an entire complex semiconductor manufacturing Fab. A comprehensive model would be of immense benefit to system designers, building operators, and building planners, among others. The current International Technology Roadmap for Semiconductors produced by Sematech includes a goal for development of such a model.

5.3.4 HVAC Systems

HVAC loads dominate the energy use in high tech facilities. In some cases 40 to 50 percent of the energy usage is attributable to the HVAC systems. With this as the largest load, it also represents the best opportunity for improvements. The following key areas represent large opportunity for energy savings:

- Exhaust:

  Exhausting conditioned air from a high tech facility represents a major cost impact for these facilities. Significant energy is expended in heating, cooling, and in some cases humidification, filtering, and scrubbing air that is then exhausted to the atmosphere. One major focus will be to minimize exhaust and thus minimize the amount of make-up air that must be conditioned. Building codes specify minimum exhaust requirements which in some cases may be based upon outdated or insufficient technical basis. With industry participation, all sources of exhaust should be examined and strategies developed to minimize or provide alternatives. This review should include code requirements and the technical basis for the requirement.

The technology used in the low flow fume hood under development has potential applications to other high exhaust areas such as gas cabinets and wet benches used in the semiconductor industry. A commercial partner, ATMI is investigating using this technology for these applications. Research to support different applications, as well as understanding and developing strategies to overcome codes and standards barriers to implementation are worth pursuing.

Another area of research is in the efficiency of scrubbers in use today. Existing equipment is far from optimal in terms of energy efficiency. Research into alternate technologies and sizing issues should be performed.

Realistic exhaust requirements for process equipment need to be developed to allow "right-sizing" of the exhaust systems. Improved control strategies for exhaust systems represent another major area for significant improvement.

- Air Recirculation:

  Air Recirculation in clean room facilities is very energy intensive. There are several aspects related to recirculation which should be investigated with the goal of reducing energy for moving large amounts of air. One area is to minimize air recirculation flow. In many cases, recirculated airflow (or air changes / time) can be reduced with no impact on the process within the clean room. Steady state reductions are possible where facilities are operating at unnecessarily high air change rates. In addition varying airflow perhaps driven by occupancy sensors, timers, or cleanliness (particle counters) could result in significant savings, especially when clean rooms are unoccupied. Studies are needed to determine theoretical and practical lower limits to airflow while still maintaining cleanliness levels.

  A new technology is proposed to be developed involving wide area laser particle detection. By continuously scanning large areas in the clean room, and being able to identify small particulates (and perhaps gases) and their location within the room, a control system could be established to optimize airflow. Such a system would be able to control HVAC systems thus saving energy. Of equal or more importance to clean room operators, would be the ability to monitor the space for hazardous materials or to verify regulatory compliance.

  The efficiency of equipment that is required to move large volumes of air is also a target of opportunity. Through partnerships with manufacturers, development of more efficient fan / filter units, more efficient recirulation fans, low face velocity fans, more efficient coils, more efficient duct systems, and more efficient filters / uniform flow filters can be accelerated.

  Research to investigate new immerging filter technologies may lead to development of revolutionary efficient HEPA / ULPA filters or a new filter technology to significantly improve filter pressure drop while assuring filter performance in terms of cleanliness and uniform flow across the filter.

Other opportunities exist in providing design guidance for more efficient ducting systems, increased use of VAV controls, and application of noise cancellation technology to reduce energy use in sound attenuation devices.

5.3.5 Strategies for Heat Recovery

Strategies for heat recovery need development. Alternative methods of heat exhaust or equipment placement and bulkheading options need investigation. Efficient burn-box technologies need development. Methods of recovering heat from waste streams should be investigated. Realistic humidity limits and ranges need to be developed with process engineer's involvement.

5.3.6 Control Systems

Control strategies and more accurate control of laboratory and clean room HVAC systems need to be investigated. Strategies to account for part-time occupancy, cleanliness levels, process loads, humidity requirements, and other factors need to be developed.

5.3.7 Mini-Environments

Energy characterization of mini-environments and potential improvements need to be studied. LBNL proposes to study the growing use of mini-environments and evaluate the potential for energy saving using this technology. Future phases should involve work with an Industry partner to adapt this technology to new applications. We would study their use within clean rooms and identify the potential for room cleanliness class changes or airflow reduction and resulting energy reduction. Improvement in the efficiency of the mini-environment itself is another area of potential research.

5.3.8 Lighting

Clean room lighting offers significant opportunity for efficiency improvements. LBNL has played a key role in developing a wide range of energy efficient lighting for various uses. New energy efficient lighting concepts for clean rooms have been demonstrated and could be developed to improve efficiency and reduce the need for maintenance. A light guide system with light (and heat) sources outside of conditioned spaces offer good potential. Additional non-energy benefits such as reduced maintenance cost are also possible. Integral with less energy intensive background lighting, LBNL will develop more efficient task lighting systems for use in these environments. Task lighting may use fiber optic or other innovative techniques for clean room compatibility. Use of daylighting and advanced lighting controls for use in clean rooms is another area for possible development. Barriers to implementation of lighting controls need to be explored.

5.3.9 Process Systems

Load Characterization and Reduction

Process Equipment loads account for the largest energy use in the majority of the floor area for these buildings. Industry specific load reduction programs can be developed targeting specific areas of process systems and equipment to improve production while reducing energy use.

Understandably, industry is reluctant to “tinker” with process systems which are critical to manufacturing in order to achieve energy efficiency. Research efforts must be made in conjunction with industry. Areas of large potential include characterizing equipment loads and obtaining realistic diversity. Inaccurate assumptions result in inefficient oversizing of mechanical systems or operating systems at inefficient part loads. Equipment manufacturers should be encouraged to implement energy efficiency improvements to major energy use equipment. LBNL can identify areas for paradigm shifts to improve energy use per unit of production.

System Efficiency

Plant utilities serving process systems often do not function optimally. One area with potential for improvement would be to standardize delivery temperatures and pressures. In some cases, one piece of equipment drives the setpoint for the entire utility system resulting in inefficiencies.

Individual system components such as motors, pumps, etc. are also targets for improvement through “right sizing” and use of most efficient products. Adapting existing programs such as DOE’s Motor Challenge, and Compressor Challenge to these facilities would also add great value. Case studies and Web-based data on best practices would be important tools for industry use.

LBNL can work with Industry to provide strategies for incremental buildout of systems, thus providing flexibility for expansion in an energy efficient manner.

Component Efficiencies

Industry should be encouraged to improve the efficiency of major equipment. By encouraging owners to require energy efficient equipment from their suppliers major improvements will occur. Owners should be encouraged to require energy efficient equipment and components through their equipment specifications. LBNL proposes to publish energy data through Web pages for major equipment. In addition, other climate and industry specific applications could be developed and published on the Web.

5.4 Collaborations

Collaboration among all organizations involved in high tech facility research, design, and operation is highly desirable. Sematech, The Institute for Environmental Sciences and Technology, ASHRAE, UC Berkeley, Arizona State University, SEMI, Northwest Energy Efficiency Alliance, EPRI, and others have on-going interest or programs in energy efficiency for high tech industries. By collaborating with industry organizations such as Sematech the work developed at LBNL and elsewhere will be more readily implemented. LBNL will propose to hold industry workshops to facilitate collaboration with industry and research organizations.

5.5 Codes and Standards

There is a need for continuing investigation of the technical basis of current codes and standards that have a major impact on energy efficiency. The goal is to identify opportunities to upgrade codes and standards according to new knowledge and technology. Further, requirements are sometimes set without a scientific basis. For example, clean room air velocity, and fume hood face velocity standards have minimal scientific justification. Specific requirements for Laboratory and clean room facilities should be studied to identify areas for improvement.

Appendix I
Design Intent Documentation

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- Design Intent Documentation Tool Instructions
- Design Intent Documentation Tool
- Design Intent Narrative (UCSC Case Study)
- Design Intent Documentation Tool New Definitions

Appendix II
Laboratory Fume Hood Containment

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- LBNL Low-Flow Fume Hood – Progress Report and Research Status
- Energy Efficient Fume Hoods
- Student Reports:
  - Low Flow Fume Hood Development Barriers
  - Low-Flow Fume Hood Project: A Look at Safety, Containment Requirements, and Test Methods
  - Low-Flow Fume Hoods: Baffles and Vortices
  - Air Flow through Woven Stainless Steel Mesh
- References to Web Pages
- Estimated Energy Savings for Ultra Low Flow Fume Hood

Appendix III
Laboratory Airflow Design

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- 1998 Report – Numerical Modeling of Air Distribution Systems
- Modeling of Laboratory Air Distribution Systems

Appendix IV
Laboratory Field Studies/Performance Feedback

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- Laboratory Field Studies / Performance Feedback
- Laboratory Energy Benchmarking Tool (MS Access Database)

Appendix V
Laboratory Design Guide

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- A Design Guide for Energy Efficient Research Laboratories – Software Documentation
- Lab Design Guide Test – Case Study Report

Appendix VI
Clean Room Benchmarks

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- Clean Room Energy Efficiency Metrics
- Metrics Table
- Case Studies on Clean Room Web Site

Appendix VII
Clean Room Analysis Tools

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- Clean Room Energy Analysis Tools
- Survey Summary
- Cleanroom of the Future: An Assessment of HVAC Energy Savings Potential In a Semiconduction Industry Facility

Appendix VIII
Clean Room Technology Transfer and Industry Liaison

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- Clean Room Energy Efficiency Workshop Proceedings
- Electronics Clean Room Energy Design Charrette Report
- Genentech Clean Room Energy Design Charrette Report

Appendix IX
Technology Transfer (General)

The appendix information is downloadable on the WWW at:

http://ateam.lbl.gov/cec.zip

Items contained in the appendix are as follows:

- CIEE Clean Rooms and Laboratories Web Site
- High Tech Buildings Brochure
- Power Point Presentation (MEUG)